

Mines and Minerals Branch Report of Activities 1988, Part B

Y. Brown and
D.R. MacDonald,
Editors

Report 89-1

Nova Scotia



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Mines and Energy**

Jack MacIsaac
Minister

John J. Laffin, D.Eng., FEIC, P.Eng.
Deputy Minister

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Editors: Y. Brown and D. R. MacDonald

Word Processing: B. L. MacDonald
L. Miller
J. Cumby
J. E. Pottie

Cartography: J. Campbell
P. Belliveau
W. Burt
G. MacDonald
C. Phillips
P. Fraser
J. Webster
R. MacPherson
W. Kaiser
E. Limpert
J. DeWolfe

Photography: C. Murphy
R. Morrison

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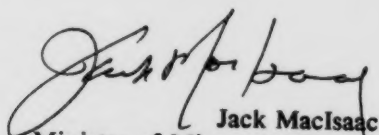
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FOREWORD

This Annual Report of Activities contains reports of field and analytical studies carried out or coordinated by the Nova Scotia Department of Mines and Energy. Most of the projects form part of a five-year, \$26 million Canada - Nova Scotia Mineral Development Agreement that was implemented in 1984. A great deal of new information on the geology and mineral resources of the Province has been collected. The Agreement, together with other programs, is designed to promote and encourage the discovery and development of Nova Scotia's mineral resources. Although it is of special interest to individual prospectors and other members of the mining community, the data collected during this Agreement are also very useful to municipal planners, hydrologists, soil scientists, environmentalists, foresters, health scientists, those involved in the construction industry, and others. Most of the field and laboratory work was completed in 1988. Reports and other material will be compiled and published in 1989-90.

A variety of mineral resources have been examined and results from this work are described in this report. Regional geological and geochemical surveys to evaluate the mineral potential over large areas have also been conducted. These activities expand the information base available to the resource sector and help strengthen our resource industries.

I commend this publication to your attention on behalf of the staff of the Department of Mines and Energy. This report presents the considered interpretations and conclusions of research at an advanced stage of project development. Our intention is to provide information that will help you understand Nova Scotia's geology and mineral resource potential.



Jack MacIsaac
Minister of Mines and Energy



ALLOGENIC CONSTRAINTS ON SITES OF PEAT-FORMING ECOSYSTEMS IN A LATE CARBONIFEROUS INTERMONTANE BASIN¹

J. H. Calder

The broad controls on the existence of peat-forming ecosystems (mires) in the geological record are regional paleogeography and structure, given appropriate evolution of the flora and a suitable climate (Teichmüller, 1982). Modern peat-forming ecosystems are similarly constrained by the topography and hydrology of the landscape (Tallis, 1983). The role of hydrologic controls in the formation of peatlands can be expressed by the general water balance equation of Ingram (1983):

$$P + N - D - E - \Delta W - n = 0$$

where P (precipitation) and N (groundwater) represent recharge to the mires, D (liquid discharge) and E (evapotranspiration) represent loss of water, ΔW represents the change in stored water and n is the error. The components of the water balance equation are the templates by which the impact of the largely allogenic influences of topography and hydrology were appraised in the formation of peat (coal) deposits within the Westphalian B (early middle Pennsylvanian) Cumberland Basin of eastern Canada.

The Athol syncline of the Cumberland Basin consists of approximately 10,000 m of Carboniferous strata, the upper 5200 m of which are nonmarine beds of Viséan to Westphalian C age (Hacquebard and Donaldson, 1964). During the Westphalian B, the basin was a major depocenter and preferential site of peat accumulation. At this time, coals originated in the Joggins and Springhill coalfields, within the Cumberland Group. This study focuses on the Springhill field, where coal seams which are relatively thick (up to 4.3 m) and of lower sulphur content (> 1.6 percent) were deposited near the southern basin margin.

Basin infilling at Springhill during the Westphalian is recorded by a 1300 m thick fining upward megasequence of the Cumberland Group, comprising the following lithofacies associations: (1) streamflow conglomerate; (2) ill-sorted pebbly sandstone; (3) thinly bedded sandstone/mudrock; (4) bivalve-bearing; (5) multi-storied sandstone/coal and (6 and 7) multi-storied sandstone/reddish

mudrock association. The paleoenvironmental interpretation of this younging basin-fill sequence is summarized as: alluvial fan ---> distal fan ---> bay-fill/wetland-lake margins ---> submerged alluvial plain with major wetland ecosystems ---> increasingly dryer alluvial plain with diminishing wetlands. This sequence can be attributed to a decreasing rate of net subsidence; climatic change (i.e. increasing aridity) need not be invoked. For the coals of the Springhill coalfield which formed near a basin margin, there existed a "subsidence window" outside of which groundwater levels were too low or high for peat accumulation (Fig. 1).

Areal reconstruction of lithofacies associations reveals a paleogeographic setting with 4.5 - 7 km wide peat mires bordered to the south by an alluvial piedmont of mature, coalesced fans. To the north of the mires, sinuous river systems occupied channel belts 1 - 2 km wide. Although the peat-forming systems held an affinity for the distal fan setting as evidenced by their preferential occurrence adjacent to the piedmont, the peat mires also exhibited a riverine affinity; thickest coals occur preferentially with multi-storied sandstone bodies (Fig. 1). Nowhere within the Springhill coalfield does a major coal occur other than between these two bordering lithosomes.

Insight into the allogenic effects of subsidence and groundwater supply on the formation of the ancient mires is supplied through analysis of the areal distribution of seams and changes in deposits of both the piedmont and major channel belts through time. The coal seams exhibit a pattern of areal distribution that varies systematically with stratigraphic position. This is most apparent above the No. 2 seam horizon as younger seams encroach progressively farther south over fining-upward fan deposits and become increasingly restricted in areal extent. The decrease in peatland area is accompanied by reddening of peripheral mudrocks.

The relationship between channel belt and mire deposits (channel sandstone bodies and coal seams) also shows systematic temporal change (Fig. 1).

¹ Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

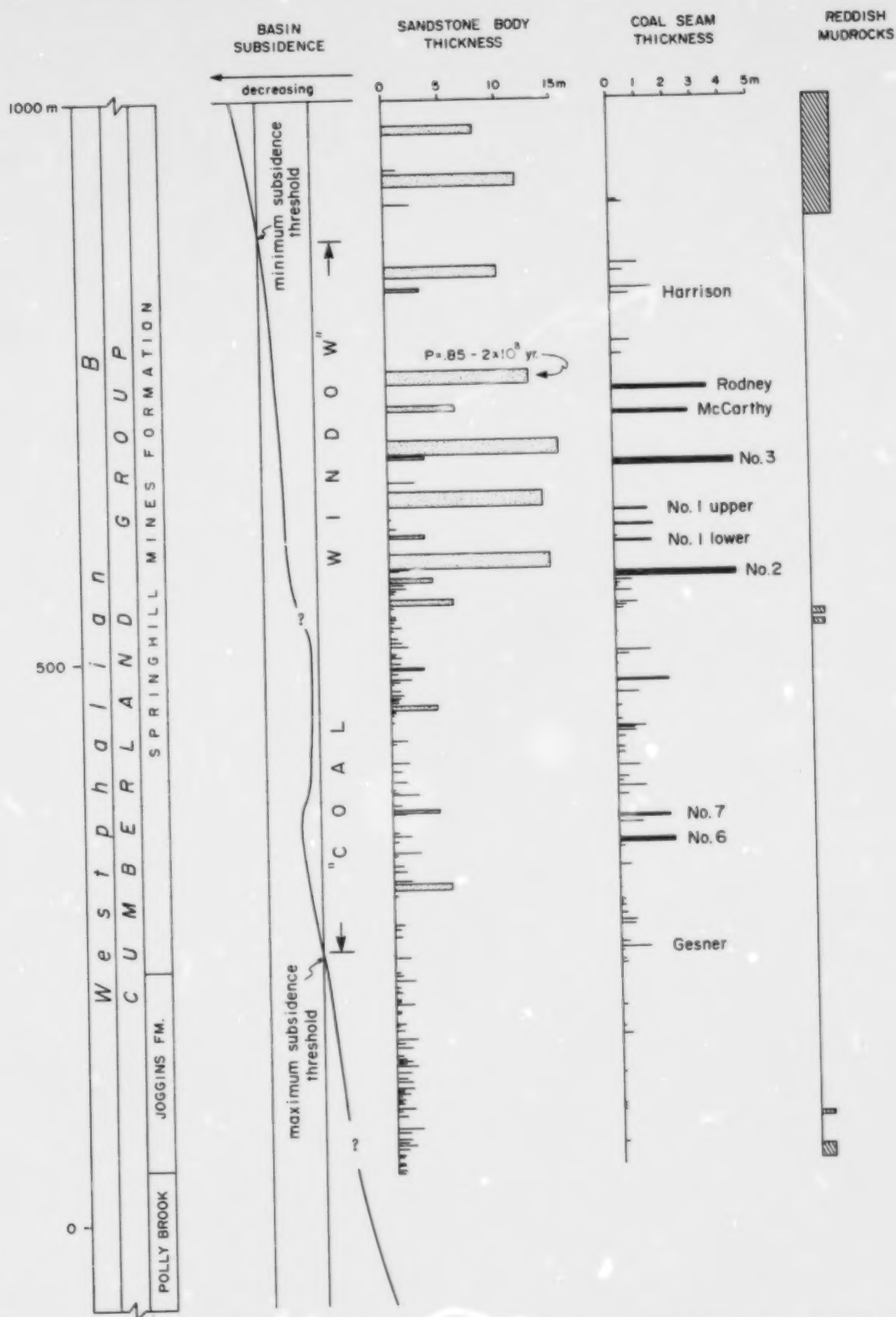


Figure 1. The basin-fill sequence of the Cumberland Group at the Springhill coalfield with interpreted coal window, in part subsidence controlled.

The maximum thickness of both increases upward, being 2-3 times greater in the upper 300 m than in the lower 300 m of the coal-bearing sequence. The increase in sandstone body thickness and decrease in stratigraphic distance between successive bodies indicates a slowing of subsidence, assuming a constant periodicity of avulsion (Allen, 1978). Continuation of this slowing trend eventually led to the formation of reddened mudrocks and a decline in peat deposition, as the basin infilled and groundwater levels dropped.

These temporal trends suggest: (1) that the peat mires became increasingly dependent upon the supply of telluric (ground) water supplied by the retreating fans of the alluvial piedmont as regional groundwater levels decreased; and (2) that optimal conditions for mire formation existed when the net subsidence rate slowed to the point where erosive amalgamation of channel sandstone bodies was commonplace. Alternatively, more development was enhanced by the presence of rivers which occupied a similar elevation to the mires for the longest time possible.

The reliance of the mires upon groundwater suggests that they were rheotrophic (groundwater fed), which is apparently at odds with the prevailing theory that Carboniferous mires which led to coal seams of commercial interest formed as ombrotrophic (rain fed) ecosystems dependent solely upon meteoric input (Moore, 1987). It is proposed herein that given suitable subsidence and basin margin quiescence, mires in at least some basin margin or intermontane settings originated as rheotrophic mires but evolved into mesotrophic to ombrotrophic ecosystems as the peat surface rose relative to groundwater level.

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MINERAL EXPLORATION MONITORING ACTIVITIES

P. D. McCulloch and J. M. McMullin

INTRODUCTION

Mineral exploration activity in Nova Scotia is monitored by the Resource Geology Section of the Mineral Development Division. Staffing consists of two geologists who are based in the regional office at Stellarton.

The monitoring process covers all exploration activities in the Province and includes regular visits to company offices and exploration sites, liaison with industry personnel and reviews of current assessment reports and other material submitted by industry. Direct liaison with industry allows the Department to maintain an awareness of current exploration activities throughout the Province. Problems and difficulties which may need to be addressed by the Department are identified and assistance or advice is provided if necessary. A statistical survey of exploration expenditures is compiled annually to obtain data on costs related to the various sectors of the mineral industry in the Province.

In addition, all drill core generated in the Province by the various mining exploration companies is recorded as part of the monitoring process. This core may be recovered for the Drill Core Library in Stellarton when no longer required by the companies.

MINERAL EXPLORATION ACTIVITY IN 1988

Mineral exploration in Nova Scotia during 1988 was down moderately from 1987 with a significant decrease in activity during the second half of the year. A preliminary estimate of \$40 million is predicted for the cost of exploration and development work conducted in the Province during the year for all minerals except petroleum. This is down from the \$45 million spent in 1987 but is still \$19 million higher than the previous record of \$21 million set in 1986 (Fig. 1). Exploration for gold accounted for the majority of the work with the remainder focused on industrial minerals, base metals and coal (Table 1).

Several factors accounted for the slowdown in activity during the second half of 1988. A large percentage of the exploration undertaken in Nova

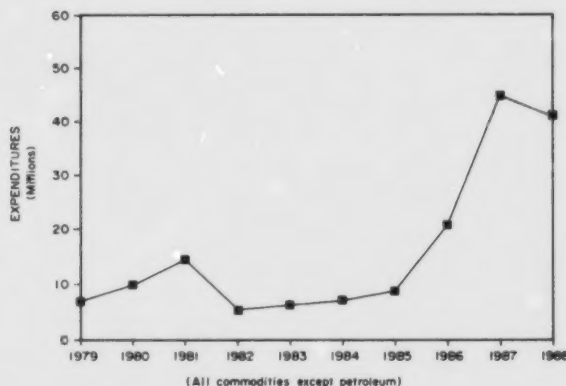


Figure 1. Graph of annual exploration expenditures, 1979-1988.

Scotia over the past three years has been carried out by junior companies with financing derived from flow-through funding. The uncertainty over the future of flow-through financing along with the negative impact of the October 1987 stock market decline and the recent weakness in the price of gold has resulted in many companies experiencing increased difficulties in raising exploration funds. In addition, a number of exploration programs have also been completed as part of the normal exploration cycle with companies now focusing efforts on the better properties.

The number of general claims staked in 1988 decreased by 38% from the previous year to 29,049 (includes both exploration and development license claims). A small increase in the number of claims staked for salt and potash and for coal was recorded in 1988. 31,768 claims for all commodities were in effect at the end of 1988, represented by 1196 exploration, development, coal, salt and potash, tailings and special licenses covering an area of 1,270,720 acres (1985 square miles or 5,142 square kilometres), roughly 9% of the total area of the Province. In addition, 12,500 claims remained closed to exploration as a result of the uranium moratorium (781 square miles or 2,023 square kilometres).

Approximately 255 companies and individuals held exploration interests (licenses or options) in the Province in 1988 including 32 major, 41 junior

Table 1. Details of exploration activity in Nova Scotia, 1979-1988.

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Total Exploration Expenditures (\$)	NA	NA	14,607,662	5,552,675	6,500,000	7,300,000	9,000,000	21,000,000	45,000,000	40,000,000
Total Licenses Issued (all categories)	1,841	2,559	1,952	1,298	1,350	1,039	1,025	1,347	1,697	1,196
General	40,497	88,703	68,863	39,626	40,630	26,627	27,809	36,714	46,482	28,646
Spec. Lic.	NA	NA	NA	NA	NA	NA	NA	NA	167	167
Coal	NA	NA	4,880	3,072	4,565	3,584	3,584	482	1,681	2,320
Current Claims										
Salt and Potash	2,256	13,505	5,225	1,065	505	1,257	830	306	192	232
Tailings	NA	NA	NA	NA	NA	NA	NA	NA	403	403
Uranium	30,920	25,483	6,225	(12,500)	(12,500)	(12,500)	(12,500)	(12,500)	(12,500)	(12,500)
Total (excl. closures)	73,673	127,691	85,193	43,763	45,700	31,468	32,223	37,502	48,925	31,768
Total Area Held Under License (acres)	2,946,920	5,107,640	3,407,720	1,750,520	1,828,000	1,258,720	1,288,920	1,500,080	1,934,220	1,270,720
Assessment Work Reported for License Renewals (\$)	4,700,000	7,564,000	8,441,270	4,107,273	4,200,210	2,625,666	2,389,351	9,954,014	26,713,524	29,612,886
Number of Assessment Reports Submitted	126	140	157	124	188	140	108	154	271	406

and 37 private companies (Tables 2 and 3). In addition, several mining lease holders carried out exploration on their leases or on unclaimed ground where these commodities did not require licenses (e.g. limestone, gypsum). Organizations actively engaged in exploration and development work during 1988 included 15 major, 20 junior and 16 private companies as well as a number of individuals.

Several companies not previously active in the Province completed exploration programs during 1988. Westminer Canada Limited continued work on the Forest Hill gold property in Guysborough County and the Beaver Dam gold property in Halifax County following the takeover of Seabright Resources Incorporated at the beginning of the year and Hecla Mining Company of Canada Limited began work on the Mooseland gold property in Halifax County optioned from Acadia Mineral Ventures Limited. Hathor Resources Limited, Midas Minerals Incorporated, Orleans Resources Incorporated and Nova Scotia-based Lotus Resources Limited also began work in the Province during the year.

Petroco of Texas Incorporated, parent company to Scotia Prime Resources Incorporated, changed its name to Scotia Prime Minerals Incorporated and moved its office to Nova Scotia in September. Torene Gold Exploration Limited changed its name to Aquagold Resources Incorporated and Wilco Mining Company Limited changed its name to Deak Resources Corporation in a corporate reorganization with Deak Ariadne Limited.

MINING EXPLORATION

GOLD

The search for gold continued to dominate exploration for metallic minerals in the Province during 1988 although the level of activity was down moderately during the second half of the year. The high expenditures for gold exploration can be partly attributed to the advanced stage of several exploration programs which have proceeded to underground exploration and development work. The continued strength and relative stability in the price of gold and the continued availability of flow-through financing in the three year period prior to 1988 played a major role in helping to sustain the recent high level of gold exploration in the Province. In addition, the Province has been an historical gold producer with a total of roughly 1.3 million ounces recovered from over 60 mining properties between 1860 and 1949.

Exploration for gold was concentrated primarily in the historic gold districts throughout southern mainland Nova Scotia where gold-bearing quartz veins occur in Cambro-Ordovician metasedimentary rocks of the Meguma Group (Fig. 2). As in other parts of the country, efforts have been concentrated on re-evaluating the known occurrences, particularly in areas of significant past production, as well as grass-roots exploration in other areas. Exploration for gold was also carried out in the Cambrian and Hadrynian volcano-sedimentary rocks of the Cape Breton Highlands.

Table 2. Major companies involved in mineral exploration in Nova Scotia.

	1986	1987	1988	Office location in 1988
BP Resources Canada Limited	x	x	x	Halifax
Canamax Resources Incorporated	-	-	-	
Conwest Exploration Company Limited	-	-	-	
Domtar Incorporated	x	x	x	Windsor
Eldorado Resources Limited (ground alienation)	-	-	-	
Esso Minerals Canada Limited	-	-	-	
Falconbridge Limited	x	x	x	Windsor
Fundy Gypsum Company Limited	x	x	x	Windsor
Georgia Pacific Corporation	x	-	x	River Denys
Granges Exploration Limited	x	x	x	
Hecla Mining Company of Canada Limited	-	-	x	Mooseland
Husky Oil Operations Limited (through Scominex*)	x	x	x	
Inco Gold Management Incorporated (manager of Scominex*)	x	x	x	Halifax
International Limestone Industries Limited (Scotia Limestone Limited)	x	x	-	Sydney
Interuranium Canada Limited (ground alienation)	-	-	-	
Lafarge Canada Incorporated	x	x	x	Brookfield
Dominion Explorers Incorporated	-	x	-	
Mosher Limestone Limited	x	-	-	Upper Musquodoboit
National Gypsum (Canada) Limited	x	x	x	Milford Station
Noranda Exploration Company Limited	x	x	x	
Nova Construction Company	x	-	-	Antigonish
Nova Scotia Sand and Gravel Limited (division of L. E. Shaw Limited)	x	x	x	Lantz
Placer Development Limited	-	x	-	
Republic Gypsum Company	x	-	-	
Rio Algom Exploration Incorporated	x	-	-	
Rio Algom Limited	-	-	-	
Suncor Incorporated	x	-	-	
Teck Explorations Limited	-	x	-	
Timminco Limited (Chromasco)	x	-	-	
U. S. Borax and Chemical Corporation (Pacific Coast Mines Limited)	x	-	-	
Westminer Canada Limited			x	
Westray Coal Incorporated			x	

x indicates work performed

- company inactive

* Scotian Mineral Exploration Venture

Highlights of the work completed during 1988 centre on the advanced surface and underground exploration programs undertaken on several properties in Halifax and Guysborough Counties. These include the Caribou, Moose River, Mooseland, Tangier and Fifteen Mile Stream gold properties in Halifax County and the Cochrane Hill, Forest Hill, Goldenville and Upper Seal

Harbour gold properties in Guysborough County.

Westminer Canada Limited (Seabright Division) continued a detailed evaluation of the Forest Hill gold property during 1988. The company completed additional underground diamond-drilling and bulk sampling at the Teasdale Mine and began underground bulk testing on the

Table 3. Junior and private exploration companies operating in Nova Scotia.

	1986	1987	1988	Office location in 1988
Acadia Mineral Ventures Limited	x	x	x	Truro
Antioch Resources (N.S.) Limited	-	-	-	
Aquagold Resources Incorporated	x	x	x	Dartmouth
(formerly Torene Gold Exploration Limited)				
Arisaig Explorations Limited		x	x	
Atlantic Goldfields Incorporated		x	-	Halifax
Aurion Minerals Limited		x	x	Halifax
Aurtec Mining Development Limited			x	
Bear Pass Resources Corporation	x	-	-	
Belore Mines Limited			x	
Benrock Limited			-	
Biron Bay Resources Limited			x	
Bluestack Resources Limited	x	x	-	
Brador Minerals Incorporated		-	-	
Breakwater Resources Limited (formerly Novamin Resources Incorporated)	x	x	-	
Carbontec Industries Limited	x	x		Halifax
Carrick Gold Resources Limited		x	x	
Cobequid Resources Limited	x	x	x	Halifax
Coxheath Gold Holdings Limited	x	x	x	Bedford
Cuvier Mines Limited	-	-	-	
Deak Resources Corporation	x	x	x	
(formerly Wilco Mining Company Limited)				
Dynamic Consolidated Resources Limited			x	
Explorer Industries Limited	-	-	-	
Fenorex Mineral Investigations Limited		x	x	Sydney River
Four Seasons Resources Limited	x	x	-	
Gedoro Mining Limited	x	x	-	Halifax
Giant Meguma Holdings Limited		-	-	
Gold Bank Resources Limited			x	
Gold Brook Developments Limited	x	x	x	Margaree
Golden Shore Explorations Limited		-	-	
Gordex Minerals Limited	-	x	x	
Greenstrike Gold Corporation	x	x	x	
Gunnar Gold Incorporated			x	
Gusto Resources Limited		x	x	Halifax
Hathor Resources Limited		-	x	
Imperial Platinum Corporation		x	-	
Jascan Resources Incorporated	x	x	x	Halifax
Kelrock Limited	x	x	x	Antigonish
Little Lake Gold Mines Limited		-	x	Dartmouth
Lodestone Limited		x	x	Halifax
Lodge Resources Incorporated	-	x	-	Dartmouth
Lotus Resources Limited		-	x	Dartmouth
Macree Resources Incorporated			-	
Magstone Development Limited	-	x	-	
Megaflo Mines & Energy Corporation	x	-	-	
Mer Resources Incorporated	x	x	-	Dartmouth
MEX Explorations Limited	x	x	x	Truro
MGB Resources Limited		-	-	
Midas Minerals Incorporated		-	x	
Middle Belt Mines Limited	x	-	-	
Minerautec Limited			-	
Mill City Gold Incorporated			x	
Mono Gold Mines Incorporated	x	-	-	
Northumberland Mines Limited	x	x	x	
Novagold Resources Incorporated	x	x	x	Halifax
Oldham Resources Limited	x	x	x	Dartmouth
Onitap Resources Incorporated	-	x	x	
Orevco Incorporated			x	
Orex Resources Limited			x	
Orleans Resources Incorporated			x	
Outland Resources Incorporated	x	-	-	
Pan East Resources Incorporated	x	x	x	
Petromet Resources Limited	-	x	x	
S. Farrell & Associates Limited		-	-	
Scotia Prime Resources Limited		x	x	Halifax
Seabright Resources Incorporated	x	x	x	Sackville
Seascope Consultants Limited		x	x	Halifax
Skyerock Minerals Limited		x	-	Antigonish
Sunrise Metals Corporation		x	x	
The Potter Mine (Nova Scotia) Limited	x	x	x	
Tournigan Mining Exploration Limited	x	-	-	
Tri-Explorations Limited	x	x	x	Dartmouth
Tusk Minerals Limited			x	
United Reef Petroleum Limited			x	
Victoria Resource Corporation	x	-	-	
W. Bruce Dunlop Limited	x	x	x	
Web Exploration Services Limited	-	x	-	
Western Land Service Company Limited	x	-	-	

x indicates work performed

- inactive

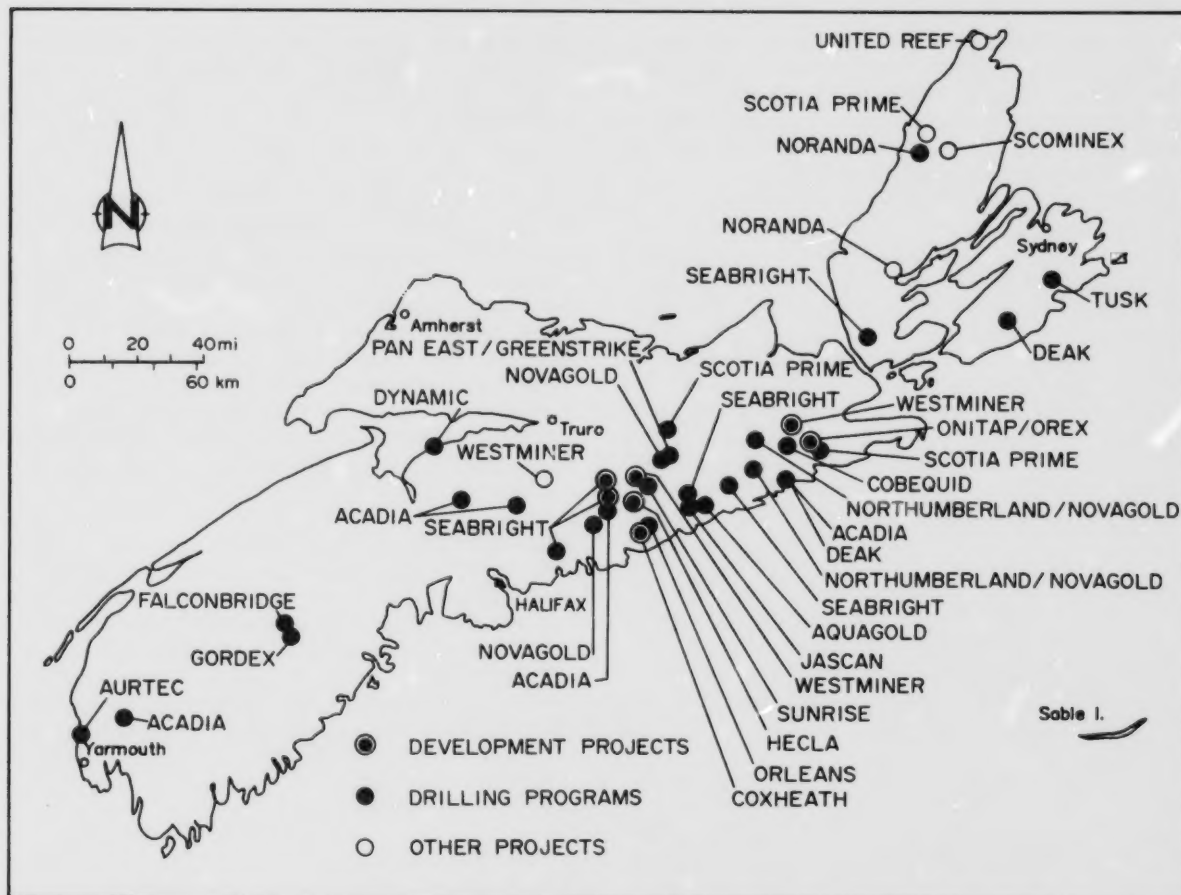


Figure 2. Location of principal exploration and development projects for gold and base metals, 1988.

Kennedy zone, 700 m east of the mine site. Western Mining of Australia acquired the assets of Seabright Resources Incorporated including the Forest Hill property in a takeover at the beginning of the year. The company also continued to evaluate the Beaver Dam gold property in Halifax County and completed additional underground bulk sample tests. Under the direction of Westminer, Seabright Explorations Incorporated continued work on the Caribou and Moose River gold properties during the year. Detailed underground mapping, sampling and diamond-drilling were carried out at Caribou to assist in the evaluation of potential ore reserves at the Holman Mine. Seabright dropped their option on the property late in the year. A development ramp was driven on the Moose River property, 2 km west of the village of Moose River, to facilitate underground bulk sampling of drill-indicated ore reserves in the vicinity of the Dr. Sutherland shaft. Surface bulk sampling was also started in the vicinity of the Touquoy mine property in the immediate vicinity of the village to test a potential

large tonnage, low grade ore zone outlined in recent drilling.

Hecla Mining Canada Limited, in a joint venture agreement with Acadia Mineral Ventures Limited, began a detailed underground exploration program at Mooseland during 1988 to assess drill-indicated ore reserves outlined in recent drilling. The company plans to complete a 360 m (1,180 ft.) shaft to facilitate bulk sampling on both the west zone in the vicinity of the old workings and the newly discovered east zone.

Coxheath Gold Holdings Limited continued the second phase of a detailed exploration and development program on the Tangier gold property during the year consisting of additional underground diamond-drilling and bulk sampling. The company also carried out additional surface diamond-drilling to test the lateral strike extension of the zone currently under development.

Onitap Resources Incorporated and joint venture partner Orex Exploration Incorporated continued a detailed exploration program on the Upper Seal Harbour gold property near Goldboro. Surface drilling has been ongoing on the property and an underground bulk sampling program was started mid-year to test drill-indicated ore reserves below the old workings. The Boston-Richardson shaft is to be deepened to access the -245 m (800 ft.) level and a 610 m (2000 ft.) decline has been collared 250 m west of the shaft.

Northumberland Mines Limited completed an underground bulk sampling program on the Cochrane Hill gold property during the first half of 1988. A decline was driven 100 m east of the Mitchell shaft to access drill-indicated ore beneath the open pit. The company also completed detailed underground mapping and sampling on the Goldenville gold property during the year. Both the Cochrane Hill gold property and the Goldenville gold property were acquired by NovaGold Resources Incorporated when Northumberland Mines Ltd. was taken over by NovaGold. Operations on the two properties were continued by NovaGold until late in the fall when work was terminated.

A number of additional surface exploration programs for gold were undertaken by several companies throughout the Province during 1988. Acadia Mineral Ventures Limited completed detailed drilling on the Wine Harbour gold property in Guysborough County, the Gold Lake and Oldham gold properties in Halifax County and the Mount Uniacke gold property in Hants County. The company also completed extensive work in Yarmouth County including diamond-drilling in the Fanning Lake and Carleton areas. Greenstrike Gold Corporation continued a large-scale drilling program on the Fifteen Mile Stream gold property during the first half of 1988 and NovaGold Resources Incorporated continued a detailed surface exploration program on an extension of the Fifteen Mile Stream gold property during the year consisting of additional diamond-drilling and surface bulk sampling. NovaGold also completed a detailed drilling program on the Lake Charlotte gold property in Halifax County.

Jascan Resources Incorporated completed extensive drilling on the Salmon River (Dufferin) gold property in Halifax County during the first half of the year and Seabright Explorations Incorporated began a detailed diamond-drilling and trenching program at Salmon River on ground adjoining the Jascan property to the north. Preparations are currently underway for Seabright to begin an underground bulk sampling program

on the property. Seabright also carried out diamond-drilling and trenching on the Lake Catcha gold property in Halifax County and the Miller Lake gold property in Guysborough County. Scotia Prime Resources Limited completed additional drilling on the Lower Seal Harbour gold property in Guysborough County and carried out a small drilling program on a property near Cameron Dam approximately 6.5 km north of the Fifteen Mile Stream gold property. Gordex Minerals Limited completed a large-scale diamond-drilling and trenching program on the Molega gold property in Queens County and Aquagold Resources Incorporated (formerly Torene Gold Exploration Limited) continued a diamond-drilling program on the Harrigan Cove gold property in Halifax County.

Cobequid Resources Limited carried out diamond-drilling on the Country Harbour gold property (Highland zone) in Guysborough County and Orleans Resources Incorporated completed a small diamond-drilling program at Strawberry Hill, 1.5 km east of the Tangier gold property. Sunrise Metals Corporation carried out a small drilling program on a property 1.5 km southeast of the Beaver Dam gold property and Aurtec Mining Development Limited carried out a small drilling program on the Cranberry Head gold property in Yarmouth County.

Scominex, under Inco Gold Management Incorporated management, continued a detailed follow-up program in the MacMillan Flowage area approximately 25 km east of Cheticamp in the Cape Breton Highlands to evaluate several gold anomalies outlined in work carried out between 1985 and 1987. In other areas of the Cape Breton Highlands, Noranda Exploration Company Limited carried out diamond-drilling on a property near Campbells Brook, approximately 12 km southeast of Cheticamp, and completed additional follow-up work on a property immediately north of Whycocomagh.

BASE METALS

Exploration for base metals has shown a moderate increase in activity over the past year with several programs undertaken throughout the Province (Fig. 2). The renewed interest in base metal exploration is due primarily to the current price levels for the primary metals which have increased significantly since the beginning of 1987. In addition, the current depletion of base metal ore reserves is providing incentive for exploration companies to focus on base metals. Several known

base metal occurrences are currently being re-evaluated with particular emphasis on carbonate-hosted environments in the Lower Carboniferous Windsor Group and Hadrynian rocks of the George River Group.

Dynamic Consolidated Resources Limited carried out a diamond-drilling program on the former barite/base metal producer at Walton, Hants County, and United Reef Petroleum Limited carried out a detailed surface and underground exploration program on the Meat Cove zinc property near Meat Cove, Inverness County. Deak Resources Corporation (formerly Wilco Mining Company Limited) completed additional diamond-drilling on the former base metal producer at Stirling, Richmond County, and Westminer Canada Limited began a detailed evaluation of the former lead/zinc producer at Gays River, Hants County. Seabright Explorations Incorporated carried out a drilling program on a property near Sugar Camp, Inverness County, and Scotia Prime Resources Limited carried out preliminary work on a property in the vicinity of LeBlanc Lake, Inverness County. Tusk Minerals Limited carried out a small drilling program on a copper property near French Road, Cape Breton County.

INDUSTRIAL MINERALS

Exploration for industrial minerals has shown a moderate increase in activity in recent years as interest continues to grow in the industrial mineral sector. Exploration for limestone and gypsum accounted for the majority of exploration activity for these commodities in 1988 and was directed primarily towards developing additional reserves on currently producing properties as well as developing new reserves in other areas (Fig. 3).

Work carried out in 1988 included the exploration and development of several limestone properties in the Maitland area, Hants County, by Lafarge Canada Incorporated and the development of new gypsum reserves in the Sugar Camp area, Inverness County, by Georgia Pacific Corporation. Domtar Limited carried out exploration drilling for salt at Nappan, Cumberland County, and also completed diamond-drilling for silica sand at McKay Settlement, Hants County. Kelrock Limited carried out bulk sampling for limestone at Glendale, Inverness County, and at Glen Morrison, Cape Breton County and Lodestone Limited completed a bulk sampling program for magnetite near Bass River, Colchester County.

COAL

Exploration for coal during 1988 was undertaken by the Cape Breton Development Corporation (Devco) at the Phelan, Langan and Prince collieries near Sydney, Cape Breton County (Fig. 3). An ongoing program of advance exploration tunnelling at the Prince colliery and borehole drilling at the Langan and Phelan collieries was undertaken during the year to test coal reserves. Aquagold Resources Limited carried out an exploration drilling program for coal on Pictou Island along the Northumberland Strait.

MINING DEVELOPMENT

GOLD

Development work was continued by Westminer Canada Limited on the Forest Hill gold property in Guysborough County during the year. The company completed a 230 m exploration shaft on the property in 1986 and began a program of underground drilling and bulk sample tests on a number of auriferous leads outlined from surface drilling. The work was continued in 1988 and included additional underground diamond-drilling and bulk sampling as well as extensive lateral development work to access drill-indicated ore.

Coxheath Gold Holdings Limited also continued development work on the Tangier gold property in Halifax County during the year. The company started the construction of a decline on the property in 1987 and began a program of underground drilling and bulk sampling to test several auriferous leads outlined from surface drilling. The work continued in 1988 and included additional underground diamond-drilling and bulk sampling. Test procedures for mining the narrow vein style of mineralization were also carried out and the company completed the construction of a mill to process bulk sample material from the underground program and to handle future mine production. The company received a mining lease for the property in December and plans to begin commercial production at a rate of 250 tons per day during the first quarter of 1989.

INDUSTRIAL MINERALS

Development drilling to expand on current gypsum reserves was continued by National Gypsum (Canada) Limited at East Milford, Hants County, by Fundy Gypsum Company Limited at Dutch Settlement, Hants County, and by Little Narrows Gypsum Company Limited at Little Narrows, Victoria County.

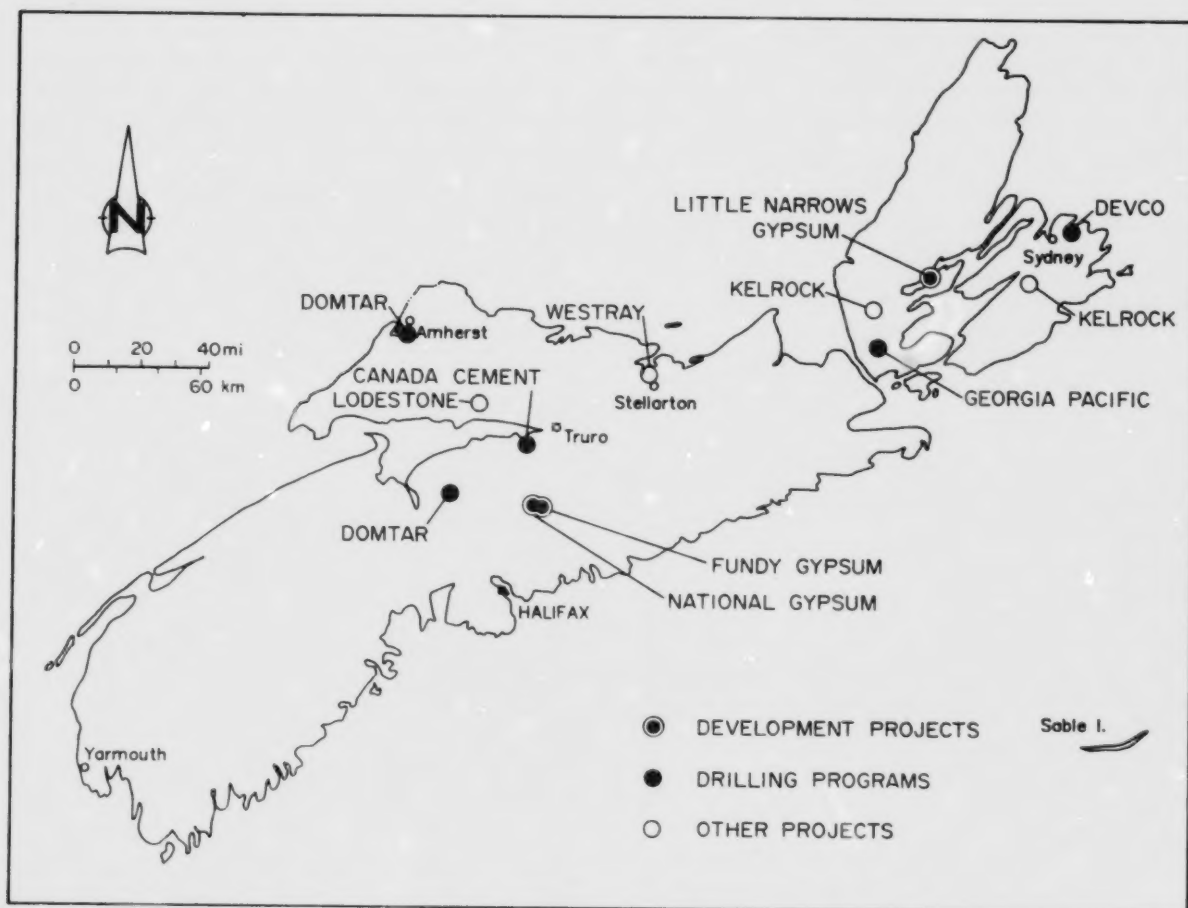


Figure 3. Location of principal exploration and development projects for industrial minerals and coal, 1988.

COAL

A production decision was made by Westray Coal Incorporated to begin construction of a new underground thermal coal mine at Plymouth,

Pictou County. The company plans to produce 1 million tonnes of low-sulphur bituminous coal annually by 1991 to supply expanded coal-fired electric generating facilities at Trenton, Pictou County.

GOLD ENRICHMENT ASSOCIATED WITH POST-MAGMATIC PROCESSES IN THE SOUTH MOUNTAIN BATHOLITH, SOUTHWESTERN NOVA SCOTIA¹

M. A. MacDonald and G. A. O'Reilly

INTRODUCTION

Potential for precious metal mineral deposits (Au, Ag) in the South Mountain Batholith (SMB) of southwestern Nova Scotia was originally suggested by O'Reilly and Chatterjee (1981) and later reiterated by O'Reilly (1983), O'Reilly (1985) and Giles and Chatterjee (1986). These workers suggest that the peraluminous, biotite-muscovite-cordierite-bearing, S-type SMB, and indeed all Meguma Zone granitoids, are compositionally similar to those found in the European and Asian Paleozoic Fold belts (e.g. French Massif Central, Bohemian Massif, Cornwall) that are host to numerous polymetallic "granophile" mineral deposits including Au and Ag.

Recent geological mapping of the entire SMB (MacDonald et al., 1988), follow-up geochemical and petrographic studies, and compilation of pertinent private-sector assessment work is nearing completion. Geochemical analyses of 456 unmineralized and relatively unaltered samples indicate an average concentration of 6.2 ppb Au (standard deviation = 11.3 ppb) in the SMB. Some low level enrichment (i.e. ≤ 50 ppb) has been noted for some samples, but the possibility of contamination of these samples has not been eliminated. Several areas within the SMB display significant enrichment of Au (e.g. ≤ 200 ppb to 10.94 ppm; Fig. 1). These areas are generally associated with polymetallic mineralization and variable amounts of post-magmatic metasomatic alteration. This report summarizes the geology of these occurrences, discusses the pertinent aspects of each one and proposes a model to explain Au enrichment in the SMB.

DESCRIPTION OF OCCURRENCES

SANDWICH POINT

A sheeted quartz vein-greisen system is exposed near Sandwich Point, along the shoreline of Halifax Harbour (Fig. 1). This occurrence was originally reported by Hattie (1959) as an

arsenopyrite-pyrite-scheelite showing which had detectable levels of Au as determined by the fire assay technique (Hattie, personal communication). Smith et al. (1986) presented trace element and rare earth element (REE) analyses for the vein system and reported the presence of sphalerite. During regional mapping of the area, MacDonald and Horne (1985) collected and analyzed several samples of the greisens (e.g. D12-7002, -7003 in Table 1) resulting in the discovery of elevated levels of Au (190, 525 ppb), W (8, 80 ppm) and Bi (30, 72 ppm). These values are for arsenopyrite-rich samples of quartz veins (e.g. As, 6.8% and 7.2%).

The greisen zone was remapped during the 1987 field season (O'Reilly, 1987; Fig. 2). The system comprises sheeted zones of parallel and bifurcating quartz veins of two main orientations, 010 and 175 azimuth, dipping 54°-74°W, and a quartz-filled fault zone striking 010° with associated quartz-muscovite greisens. The entire greisen-vein system has a true strike width of 122 m and an exposed length along the shoreline of 268 m and is therefore one of the best exposed greisen systems in the SMB. Individual zones may attain 8 m in strike width (Fig. 2). Analyses of samples collected during this mapping confirm the previously reported Au, Bi and As enrichment (e.g. D12-87-G020, -G022 in Table 1; sample locations on Fig. 2).

As part of a study of the chemical and oxygen isotope evolution of the SMB, Kontak et al. (1988) collected samples of quartz and K-feldspar from two greisens at Sandwich Point. The sample of quartz has a calculated $\delta^{18}\text{O}$ value of 11.5-14 ‰ based on quartz-water fractionation for a temperature of 300-400°C (see Kontak et al., 1988 for discussion). This value is significantly higher than the average values reported for the SMB (Longstaffe et al., 1980; Chatterjee et al., 1985; Kontak et al., 1988) and was interpreted as representing either "metamorphic-derived water or fluid which equilibrated isotopically with the nearby metasedimentary rocks".

¹ Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

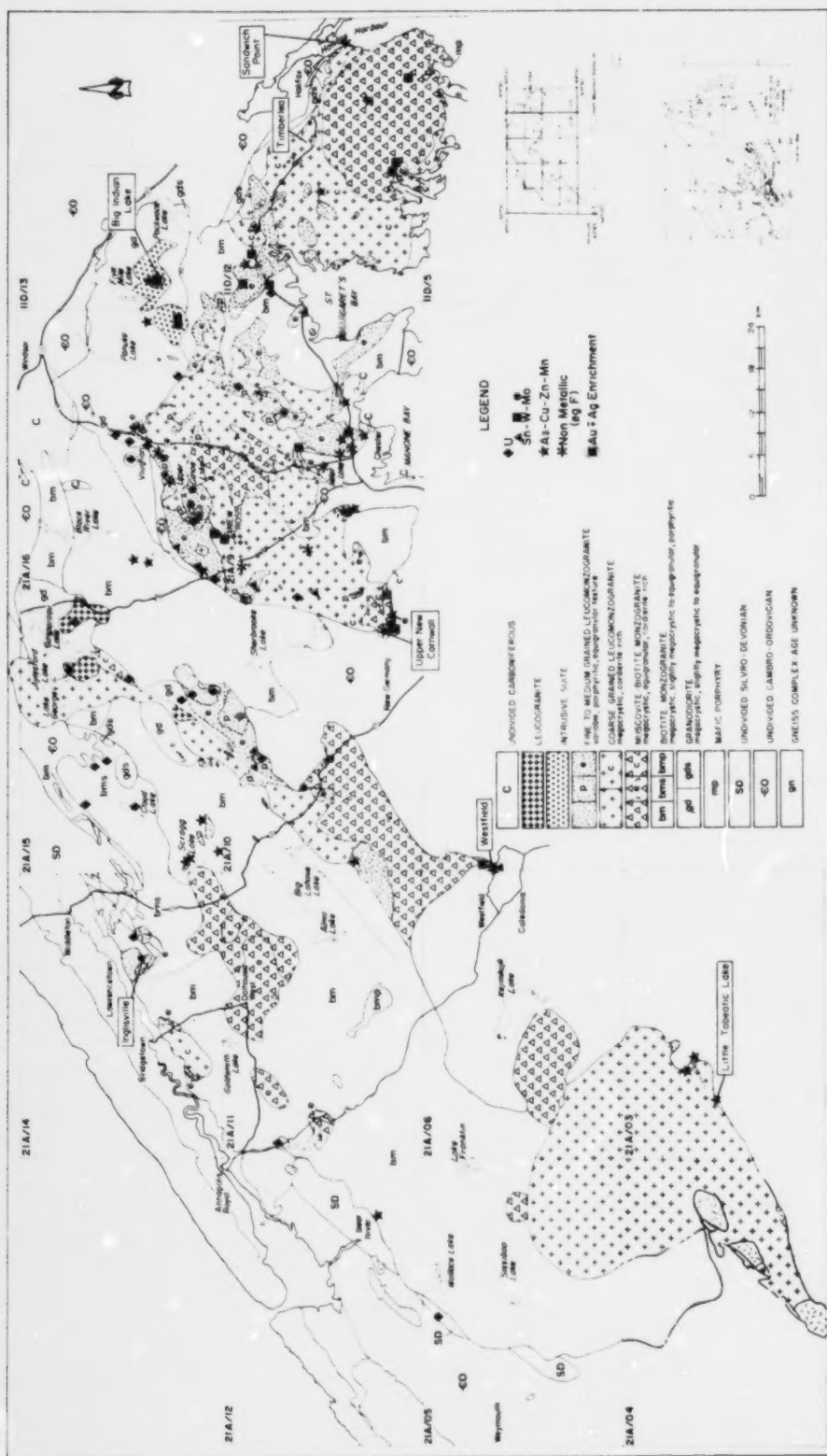


Figure 1. Geological map of the South Mountain Batholith outlining all known mineral occurrences and the location of the 8 study areas referred to in the text.

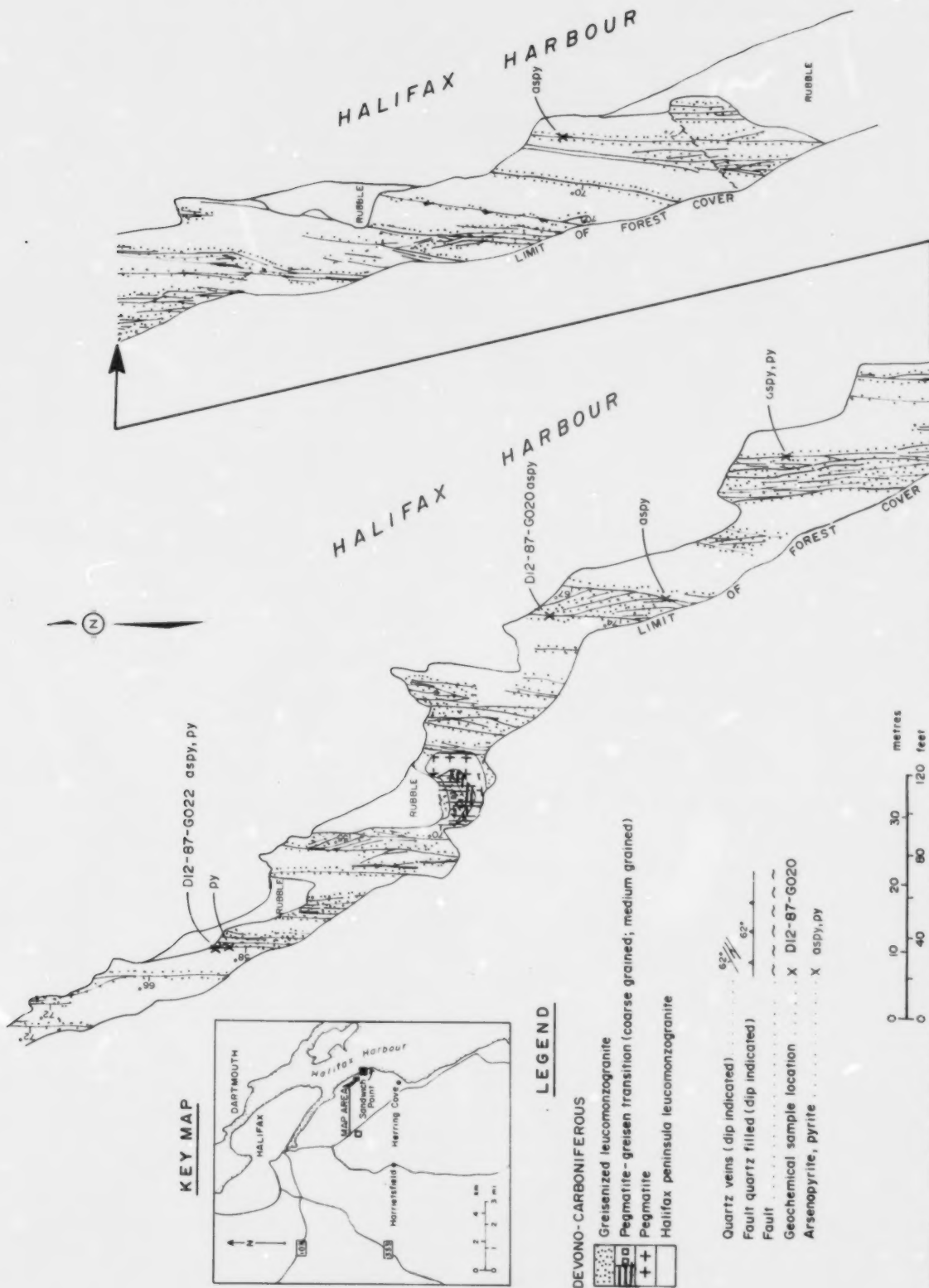


Figure 2. Detailed geological map of the Sandwich Point area outlining the distribution of greisen-bordered quartz veins and a pegmatite dyke. The map also gives geochemical sample locations (Table 1) and occurrences of arsenopyrite and pyrite.

Table 1. Selected geochemical analyses with enriched levels of Au from the South Mountain Batholith.

AREA	SANDWICH POINT				ROACHS POND	GOVERNOR LAKE	UPPER NEW CORNELL	BIG INDIAN LAKE		INGLISVILLE		WESTFIELD		
SOURCE	1		2		2	3	2	4	5	6	7			
SAMPLE NUMBER	D12-7002	D12-7003	D12-87-G020	D12-87-G022	SPY-2A	09-23-07	A10-87-G011	A10-87-G013	D13-2093-1	SNB - 1	A14-C015	A14-C017A	A7C-7530	A7C-7584
MAJOR ELEMENTS (%)														
SiO ₂	-	-	-	-	-	-	-	71.08	88.52		97.59	89.16	70.56	69.61
TiO ₂	-	-	-	-	-	-	-	0.90	0.02		0.02	0.04	0.55	0.63
Al ₂ O ₃	-	-	-	-	-	-	-	14.25	0.68		1.61	5.89	14.86	14.89
Fe ₂ O ₃	-	-	-	-	-	-	-	4.22	2.86		0.75	2.43	3.23	3.27
MnO	-	-	-	-	-	-	-	0.02	0.39		0.02	0.07	0.04	0.10
MgO	-	-	-	-	-	-	-	0.76	0.75		0.72	0.82	0.79	0.90
CaO	-	-	-	-	-	-	-	0.27	0.03		0.00	0.00	0.43	1.56
Na ₂ O	-	-	-	-	-	-	-	2.07	0.28		0.62	0.92	4.19	4.33
K ₂ O	-	-	-	-	-	-	-	3.51	0.07		0.24	0.40	3.45	3.29
P ₂ O ₅	-	-	-	-	-	-	-	0.23	0.02		0.02	0.02	0.16	0.21
LOI	-	-	-	-	-	-	-	2.03	0.50		0.20	0.90	1.45	1.10
TRACE ELEMENTS (ppm except Au ^a - ppb)														
Be	-	-	16	<5	250	98	100	490	0	50	8	13	640	400
Ba	334	130	66	<5	66	57	66	300	11	21	62	75	248	210
Rb	-	-	<5	<5	-	-	<1	3	0	11	<5	<5	80	102
Sr	-	-	<1	<1	34	27	80	<490	94	11	<1	<1	-	-
Hf	-	-	23	7	-	-	<0.5	1.3	12	6.6	39	37	-	150
Zr	-	-	<0.5	<0.5	1.3	3.8	-	-	5.0	5.8	27	34	-	-
Ta	-	-	5	<5	-	10.0	-	7.2	38	6.6	10.0	9.2	-	-
Hb	-	-	0.5	<0.2	5.7	-	1.7	-	3.5	5	4.8	5.0	-	-
Sc	-	-	<5	<5	-	-	-	-	0	5	5	-	-	-
V	-	-	<5	<5	-	160	38	20	2	<2	<2	<2	-	-
La	-	-	<19	<12	606	-	-	-	1	<2	<5	<5	-	-
Y	-	-	16	<5	-	-	-	-	23	12	6	12	-	-
Ce	-	-	0.9	0.4	35.5	23.6	4.5	14.0	1.9 (24.1)	0.2 (3.6)	3.6 (24.15)	2.9 (14.26)	7.0	7.5
Th	-	-	<4.5	<3.5	6.9	4.7	<5.4	7.7	3.0	2.7	17.0	20.2	4.7	6.6
U	-	-	8	<1	39	-	-	84	11	11	11	32	61	103
Li	110	58	240	330	250	-	-	640	70	110	258	588	430	700
F	-	-	64	17	40	-	-	53	25	30	168	3342	36	-
B	-	-	105 000	8500	116	6.9	14 000	<9000	16	<6.8	126	111	-	-
As	72 000	68 000	105 000	396	89	811	2010	180	223	565	447	690	10 940	10
Au ^a	190	525	531	396	22	7	7	90	10	5	5	8	36	4
Sr	63	40	15	6	9	2	<2100	44	51	30 000	708	410	11	11
W	80	8	7	9	-	-	-	-	151	30 000	<5	<5	102	37
Cu	50	6	113	54	-	-	-	-	13	100	75	39	16	21
Pb	12	8	27	10	-	340	154	41	15	12	46	66	95	90
Zn	48	17	32	24	<170	-	328	1	467	2387	1336	139	3.6	0.0
Bi	30	72	36	12	7	7	<17	44	13	11	23	0.3	3.0	3.0
Mo	-	-	<14	<12	<5	7	11	0.1	<4	2.3	<0.1	0.3	0.8	30.0
Ag	0.4	0.8	0.8	17.5	10	<4	21.8	2.3	0.3	0.3	2.7	2.0	-	-
Sb	11	13	44.0	-	3.7	6.0	-	-	<0.3	0.5	2.7	-	-	-

1 unpublished data M. A. MacDonald

2 unpublished data G. A. O'Reilly

3 unpublished data C. Miller

4 H. L. J. Marsh, S. J. Corey, M. C., Horne, R. J. and MacDonald, M. A., 1989

5 unpublished data P. K. Smith

6 unpublished data M. A. MacDonald and C. Cormier

7 O'Reilly, G. A., 1983

N.B. High levels of Th (in brackets) were determined by XRF techniques and represent "contamination" from high levels of another element (8, 7)

ROACHS POND AND TIMBERLEA

Two occurrences of amethyst-bearing silicified breccias were investigated in the Roachs Pond (RP) and Timberlea (TM) areas (O'Reilly, 1987; Fig. 1). Both the RP and TM occurrences display multiply superimposed periods of silicification and brecciation which are presumably associated with movement along the Herring Cove Fault (MacDonald and Horne, 1985). The abundant silicification indicates that the fault acted as a conduit for abundant silicic fluids. Samples of a pyrite-marcasite-bearing grey, siliceous, vuggy, breccia from RP contain minor enrichment in Au (89 ppb), the highest reported concentration of La in the SMB (sample Spy-2A, 606 ppm; Table 1) and minor enrichment in several other REEs (e.g. Eu, Yb - 12, 4.7 ppm, not given in Table 1). This enrichment in REEs may reflect the occurrence of a high relief, high birefringent mineral tentatively identified as monazite in several thin sections from RP. Analyzed of samples from TM contained low levels of Au, however a pan concentrate from the western end of Governor Lake approximately 0.5 km east of TM (Craig Miller, personal communication) returned 811 ppb Au and 180 ppm La (Table 1) and therefore has a similar geochemical signature as the RP occurrence.

BIG INDIAN LAKE

The Big Indian Lake Polyphase Intrusion (BIPI) which outcrops in the northeastern section of the SMB (Fig. 1) comprises a series of extensively metasomatized and texturally variable rock types hosting shear-controlled U mineralization and polymetallic quartz veins (Corey, 1987; Fig. 3). The BIPI contains abundant roof pendants of granodiorite which in turn contain large xenolithic blocks of Meguma Group metasediments (up to >10 m in diameter), thus implying that the present level of erosion is near the roof of the SMB.

Elevated levels of Au (565 ppb; SMB-1 in Table 1) have been reported from a greisen-bordered quartz vein from the BIPI (Corey, 1987). The vein contains coarse wolframite crystals (1-7 cm long), disseminated scheelite, chalcopryrite and trace amounts of molybdenite which are reflected in elevated W, Cu and Mo (3%, 151 and 13 ppm respectively, Table 1). A semi-quantitative microprobe analysis of a gold-coloured metallic mineral returned 84% Bi, 2.9% W and up to 0.5% Au, with minor amounts ($\leq 0.5\%$) of FeO, MgO, MnO and CaO (Corey, personal communication). The actual mineral species has not been determined but its presence marks the first documentation of a gold-bearing mineral within the SMB. The high

value of Bi in sample D13-2093-1 (Table 1) presumably reflects the presence of this mineral.

UPPER NEW CORNWALL

Exploration by Kidd Creek Mines Ltd. in the Upper New Cornwall area (Fig. 1) resulted in the discovery of numerous polymetallic mineral occurrences, one of which contained 970 ppb Au and elevated As, Ag, Sn and W (Corey, 1983). The mineral occurrences consist of northwest-trending greisen-bordered quartz veins, quartz and quartz-greisen boulders and albitites and albitized granites which cluster near the granite/metasediment contact (Fig. 4). Economic minerals include one or more of the following: arsenopyrite, pyrite, sphalerite, chalcopryrite, bornite, covellite, molybdenite and wolframite. The host rocks are the Whale Lake megacrystic muscovite-biotite monzogranite and the New Cornwall syenogranite (Horne, 1987).

Several mineral occurrences were resampled and submitted for multi-element analysis (O'Reilly, 1987). The results for the 2 samples with the highest Au (2010 and 180 ppb) are given in Table 1. The elevated levels of As, Ag and W (14 000, 11 and 180 ppm) confirm Kidd Creek Mines Ltd.'s original results. Sample A10-87-G011 contains 328 ppm Bi which suggests the possible presence of a bismuth mineral as seen in the BIPI. An occurrence of bismuthinite-chalcopryrite-molybdenite north of Caribou Lake in the New Cornwall syenogranite was reported by Sinclair (1978), however, attempts to confirm this showing were unsuccessful (Horne, 1987).

INGLISVILLE

The Inglisville area (Fig. 1) was mapped during the 1988 field season (MacDonald et al., 1988). Two separate bodies of fine grained leucomonzogranite which may be connected at depth, are separated by a thin septum of black slates of the Halifax and White Rock Formations (Fig. 5). A series of superimposed greisens are developed along the northwest side of the metasedimentary wedge (Fig. 5; Cormier, 1989). These greisens consist of a pervasive hematized quartz, muscovite, garnet $\pm$ albite $\pm$ chloritoid and a later(?) superimposed series of zoned greisens consisting of a rim of quartz + minor muscovite $\pm$ tourmaline $\pm$ garnet $\pm$ bismuth mineral $\pm$ molybdenite, surrounding a core of massive tourmaline $\pm$ muscovite. These greisens rarely exceed 0.5 m wide and are commonly linked in a "pinch and swell" pattern. The greisen package has been traced for approximately 50 x 30 m and is assumed to parallel the contact (Cormier, 1989).

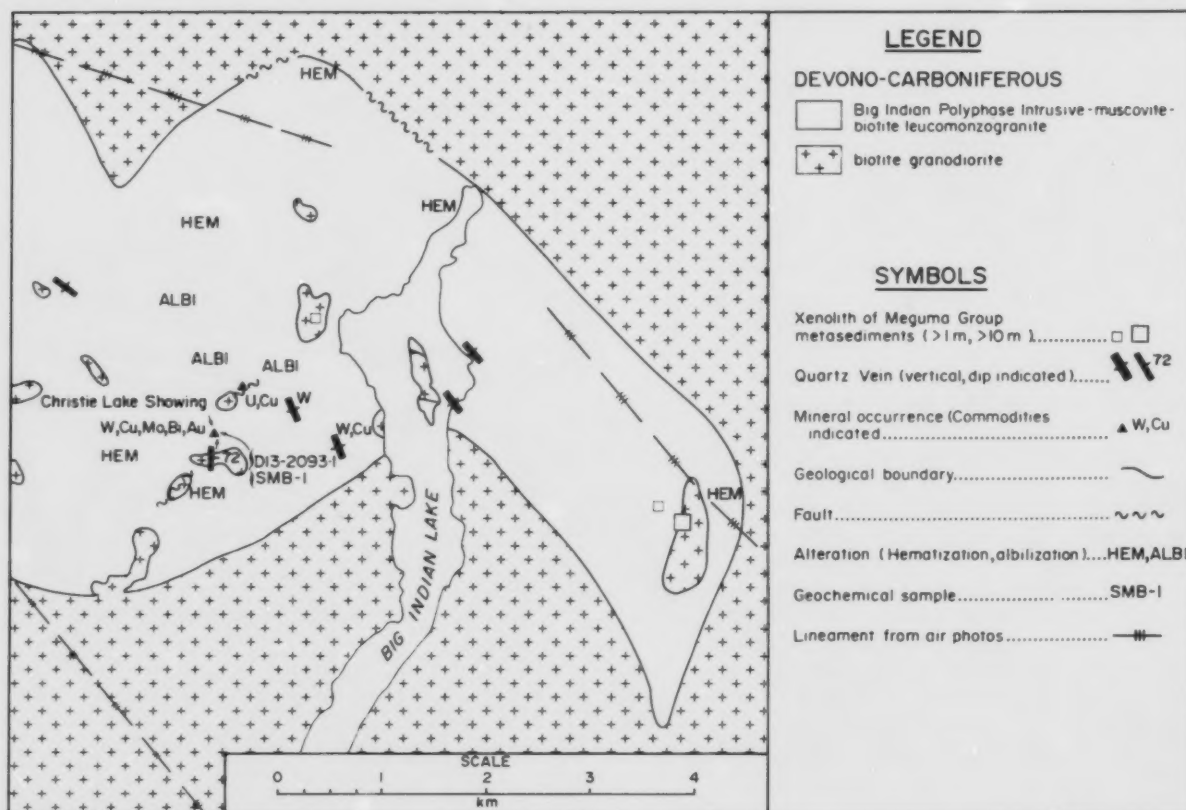


Figure 3. Detailed geological map of the Big Indian Lake Polyphase Intrusion (BIPI) (modified after Corey, 1987) displaying the locations of mineral occurrences, geochemical samples from Table 1, quartz veins, alteration zones, roof pendants of granodiorite and large xenoliths of Meguma Group metasediments (i.e. >1 m, >10 m).

A suite of samples from this area was collected by C. Cormier as part of a B.Sc. (Hon.) thesis at Saint Francis Xavier University, Antigonish, Nova Scotia. Geochemical analyses indicate that 2 samples of the quartz greisen (with minor muscovite and tourmaline $\pm$ molybdenite) are enriched in Au (690 and 447 ppb; Table 1). Other elements that are enriched include W, Ta, Nb, As and Mo with maximum values of 708, 10, 34, 126 and 139 ppm. A high level of B (up to 3342 ppm) reflects the presence of tourmaline. As is low compared with Sandwich Point and Upper New Cornwall, reflecting the relative absence of arsenopyrite. The two samples from Inglisville (Table 1) contain the highest reported values of Bi in the SMB. Semiquantitative microprobe analysis of a gold-coloured metallic mineral (Cormier, 1989) indicates that it is a bismuth mineral which may be the same species as that reported in the BIPI. The high Th values by the XRF method for samples D13-2093-1, A14-C015, A14-C017A which are given in brackets in Table 1 are probably false and reflect interference from Bi (Cameron, personal communication).

WESTFIELD

Gold mineralization in the Meguma Group-hosted Jumbo vein near Westfield (Fig. 1) has been known since 1888 (Malcolm, 1976). O'Reilly (1983) noted the presence of Sn-W mineralization in and around this alteration-bounded quartz vein and proposed a genetic link with the nearby SMB. Further geological mapping indicated that the nearby embayment of granitic rocks is extensively metasomatized with albitization and local quartz-muscovite greisenization predominating near the granite/metasediment contact and K-feldspathization in central regions of a leucomonzogranite porphyry (Fig. 6). A sample of this "paraintrusive" granite porphyry returned 10.94 ppm Au with slightly elevated Cu and Sn (102 and 36 ppm respectively). Sulphide-bearing quartz veins within the "paraintrusive" rocks also contain elevated Ag and Au. O'Reilly (1983) considered the geology of Westfield similar to an area in the French Massif Central where Au mineralization is interpreted as originating from the 2-mica leucomonzogranites and muscovite leucogranites

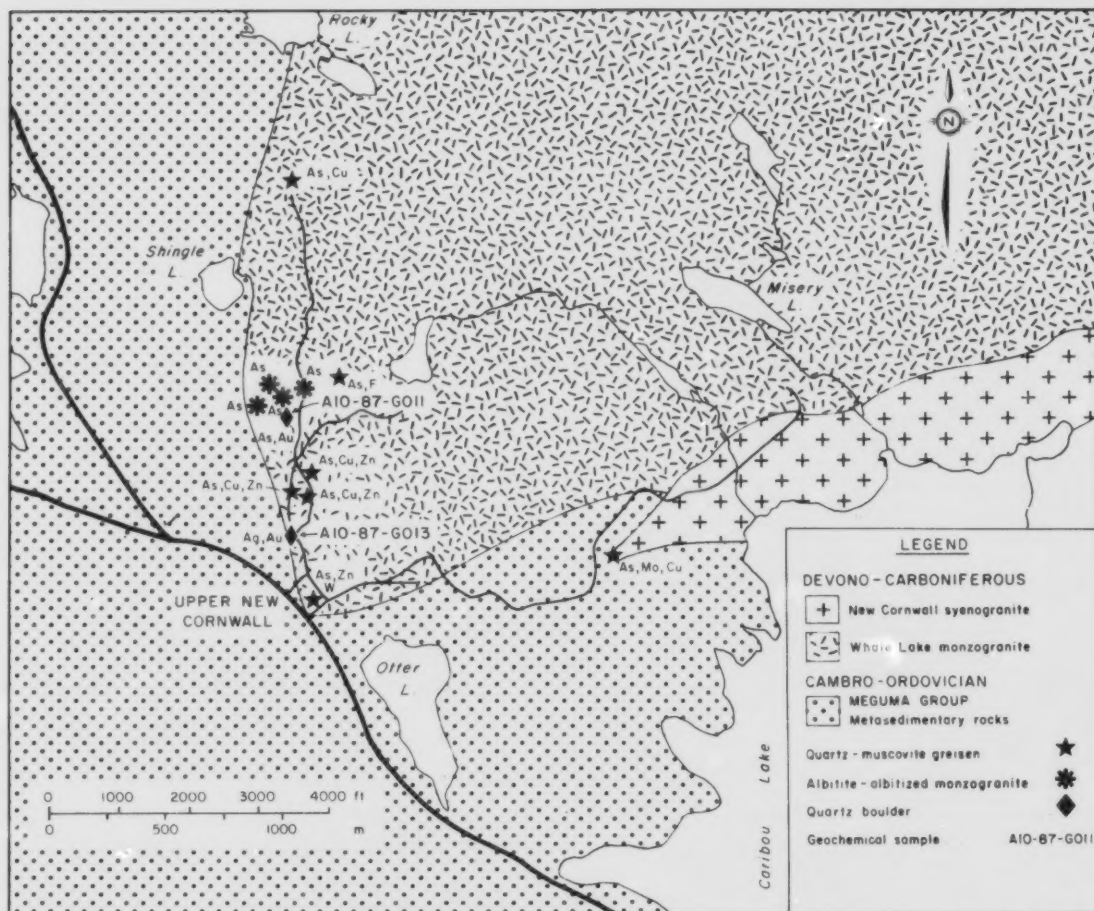


Figure 4. Detailed geological map of the Upper New Cornwall area (geological boundaries after Horne, 1987). Locations are given for mineral occurrences and geochemical samples from Table 1.

(Crouzet et al., 1979). Analyses of samples collected later from this area could not substantiate the enrichment of Au in the porphyry.

O'Reilly (1985) reports a slight elevation in Au from a quartz-albite porphyry (10 ppb) and a composite quartz-albite-chlorite-pyrite porphyry dyke with Sn-W mineralization (≤ 73 ppb) from the nearby Caledonia area. Both of these dykes intrude Meguma Group metasediments, however, they are proximal to a pronounced gravity low which O'Reilly (1983) interpreted as reflecting a buried granite cupola.

LITTLE TOBEATIC LAKE

Exploration by Billiton Canada, Ltd. (Dickie and Zwicker, 1983) and B.P. Resources Canada, Ltd. (McKenzie, 1988) and geological mapping during the 1988 field season (Corey, this volume) has outlined an extensively silicified, kaolinized, hematized and brecciated shear zone with

associated arsenopyrite, galena, sphalerite and barite near Little Tobeatic Lake (Fig. 1). This zone extends along the southern margin of the SMB and coincides with the trace of the proposed Tobeatic Fault Zone (TFZ) of Giles (1985). A complete description of the exploration history, mineralization and polymetallic-precious metal potential of the area is given in Corey (this volume). Samples of an arsenopyrite-pyrite-bearing silicified breccia boulder from the TFZ, which were collected by Billiton Resources Canada, Ltd., returned 2035 ppb Au (Dickie and Zwicker, 1983). Corey (this volume) indicates an area with coincident Sn-W-Pb-Zn-Ba-Au anomalies in whole till samples collected along and south of the TFZ. These anomalies occur over predominantly Meguma Group metasediments, however, the "granophile" signature of the anomalies coupled with abundant granite clasts in nearby tills and elevated U/Th radiometric response (see Corey, this volume, for discussion) suggests a possible granitic source for these anomalies.

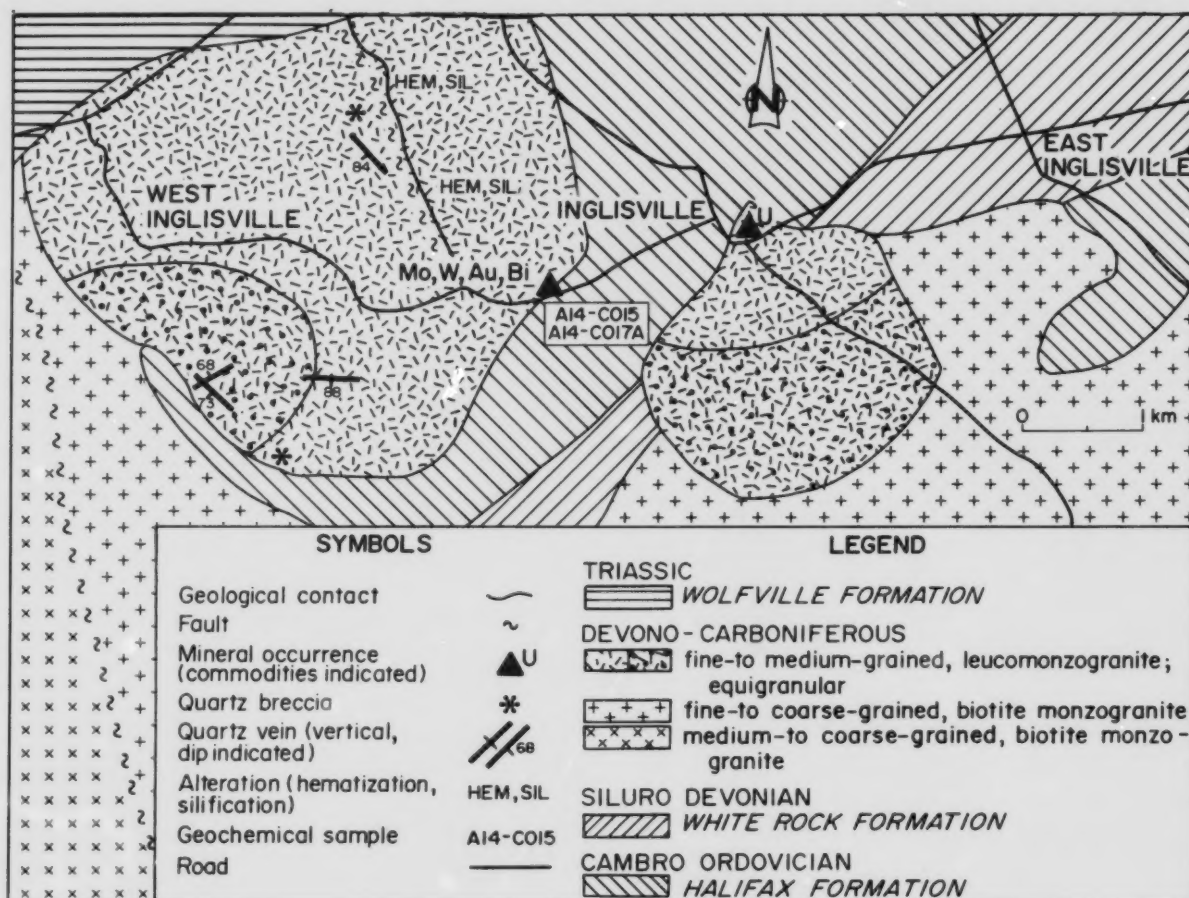


Figure 5. Detailed geological map of the Inglisville area (MacDonald and Ham, personal communication) with locations of mineral occurrences and geochemical samples from Table 1.

DISCUSSION

The previous section outlined all areas with significant gold enrichment (e.g. 89 to 10 940 ppb) in the SMB which have been determined from recent work (O'Reilly, 1985, 1987; MacDonald et al., 1988). It should be stressed that not all of the known mineral occurrences in the SMB have been sampled and analyzed for Au and therefore this may only represent a partial list. Some common features of these occurrences are summarized in the next section.

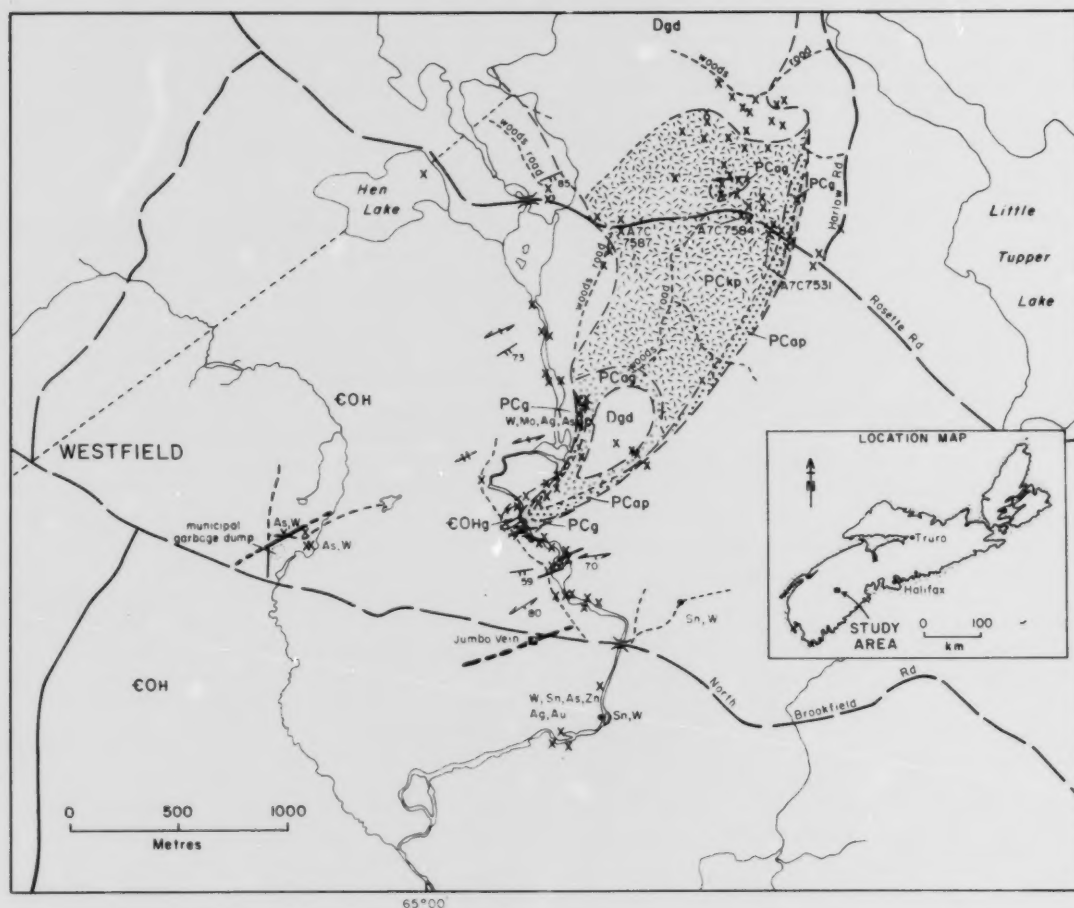
PROXIMITY TO GRANITE/METASEDIMENT CONTACT

Perhaps the most striking feature of the occurrences is the close proximity of five of them to the contact with the Meguma Group metasediments (e.g. Sandwich Point, Upper New Cornwall, Westfield, Inglisville and Little Tobeatic

Lake). The presence of large blocks of Meguma Group rocks in granodiorite roof pendants in the BIPI suggest that it too was proximal to the roof zone of the SMB. The Little Tobeatic Lake occurrence is dominantly in the metasedimentary rocks of the Meguma Group, however, the fault also crosscuts the granitic rocks of the SMB nearby.

ASSOCIATION WITH MAJOR STRUCTURAL FEATURES

The RP and TM occurrences are located along the Herring Cove Fault (MacDonald and Horne, 1985) which extends from Herring Cove on NTS map sheet 11D/12 to Big Indian Lake on NTS map sheet 11D/13 (Corey, 1987), a distance of >40 km. The Little Tobeatic Lake occurrence is found along the TFZ which has a proposed length of 400 km (Giles, 1985). The extensive fracture-controlled silicification with episodic deposition of quartz (including amethyst and smoky varieties) observed



PERMO - CARBONIFEROUS

PCog, PCap, PCap, PCg Altered granodiorite-monzogranite (PCog); k-feldspathized porphyry (PCap); albitized porphyry-albitite (PCap); greisenized granite-greisen (PCg).

DEVONIAN

Dgd

Biotite granodiorite-monzogranite

CAMBRO-ORDOVICIAN

COH, COHq

MEGUMA GROUP

Halifax Formation: green slate, phyllite, minor quartzite, hornfels (COH); greisenized country rock and quartz-muscovite-tourmaline greisen (COHq)

COG

Goldenville Formation greywacke, quartzite, minor slate

Geological boundary (defined, approx., assumed)

Bedding, tops unknown (inclined, vertical)

Foliation (inclined, vertical)

Outcrop

Quartz vein (stockwork, fissure)

Mineralized boulders

Sample no. (chemically analysed samples)

Shaft

Figure 6. Detailed geological map of the Westfield area (after O'Reilly, 1983) outlining the distribution of the K-feldspathized porphyry, albitized porphyry and greisenized granite. Locations are given for the Jumbo vein, polymetallic Sn-W mineral occurrences and geochemical samples from Table 1.

at the above occurrences indicates that these faults were conduits for abundant silicic fluids. The superimposition of brecciation and silicification dictates that the faults were active during this fluid influx.

METASOMATIC ALTERATION

Varying degrees and styles of metasomatic alteration have been observed at all occurrences including: vein(quartz)-bordered, quartz-muscovite

greisenization at Sandwich Point; quartz-muscovite-tourmaline-garnet greisenization at Inglisville; K-feldspathization, albitization and quartz-muscovite greisenization at Westfield; albitization and vein(quartz)-bordered quartz-muscovite greisenization at Upper New Cornwall; and K-feldspathization, albitization, garnetization and high alumina hydrothermal alteration (predominantly andalusite) in the BIPI. These are typical "granite type" alterations present throughout the SMB, implying that late-magmatic hydrothermal fluids attended Au enrichment. This interpretation is not unequivocal as similar alteration effects can conceivably be attained, for example, by metamorphically-derived fluids (Kontak, personal communication).

ASSOCIATED MINERALOGY

Most occurrences have associated sulphide minerals which include pyrite $\pm$ arsenopyrite $\pm$ chalcopyrite $\pm$ galena $\pm$ sphalerite $\pm$ covellite $\pm$ bornite. These minerals may be found in igneous, metamorphic or sedimentary rocks and have numerous possible origins (e.g. magmatic, hydrothermal, epithermal, etc.; Deer et al., 1966). Therefore, their presence in the above occurrences does not yield conclusive genetic information. Conversely, numerous minerals which are commonly "granitic" in origin (e.g. tourmaline (schorl-elbaite variety), fluorite, wolframite, scheelite, molybdenite, monazite) are also present. Although not unequivocal proof, their presence implies that a residual granitic fluid/melt was integral to the enrichment process.

GEOCHEMISTRY

The enrichment in "chalcophile" elements (e.g. As, Cu, Pb, Zn) does not shed light on the genesis of these occurrences as these elements may be enriched and deposited by hydrothermal, epithermal or even surficial processes. However, enrichment in elements generally considered to be "granophile" in nature (e.g. F, B, Sn, W, Th, La, Ta) supports the involvement of late-magmatic hydrothermal fluids at these occurrences.

GOLD IN GRANITE: A POSITIVE ID

The recognition and semi-quantitative analyses of a Bi-W-Au mineral in the quartz-wolframite vein (i.e. D13-2093-1) from the BIPI (Corey, personal communication) represents the first documentation of a Au-bearing mineral phase in any granitoid rock of the Meguma Zone. The

presence of this mineral is reflected in the high Bi value for sample D13-2093-1 (467 ppm; Table 1). Coincident anomalies of Au and Bi at Sandwich Point, Upper New Cornwall and Inglisville, which also has a gold-coloured metallic mineral, suggests that this mineral may be the site for Au at these locales.

MODEL

Any proposed model for the observed enrichment of Au in the granitic rocks of the SMB must consider all of the above points. The model favoured by the authors is presented in Figure 7. In it the SMB acted as a heat source to drive convective (?) circulation of fluids in and around the batholith. The SMB provided late-magmatic fluids, enriched in granophile and possibly chalcophile elements, that rose (along mineral grain boundaries ?) to apical portions of the batholith. The granitic magmas may have provided some of the Au as proposed by Crouzet et al. (1979) for the deposits in the French Massif Central. Oxygen isotope evidence from Sandwich Point (Kontak et al., 1988) dictates that fluids were also derived from, or interacted with, metamorphic rocks which could be either the surrounding Meguma Group or underlying basement rocks (Kontak and Smith, 1988). These fluids interacted with metasedimentary wall rocks and presumably "leached" chalcophile and precious elements. Leaching of Au from country rocks surrounding major batholithic bodies has been proposed by numerous authors including Utter (1982) and Mann (1982) for Au deposits in Colombia and Zimbabwe respectively. The SMB-derived and metamorphic fluids then intermixed and ascended to the relatively impermeable granite/metasediment contact which acted as a locus for fluid accumulation. This ponding of fluids caused variable degrees of metasomatism and deposition of mineralization. Periodic and/or continuous breaching of the impermeable metasedimentary cap would facilitate the escape of hydrothermal fluids from these reservoirs. This process would explain such features as the Jumbo vein at Westfield, the extensive silicification at Little Tobeatic Lake and the occurrence of extensive alteration zones in the Meguma Group rocks. The RP and TM occurrences which do not occur near a known or inferred granite/metasediment contact presumably occur farther "down" structures similar to that at Little Tobeatic Lake (Fig. 7).

CONCLUSIONS

Gold enrichment has been documented for several areas, which are intimately associated with varying

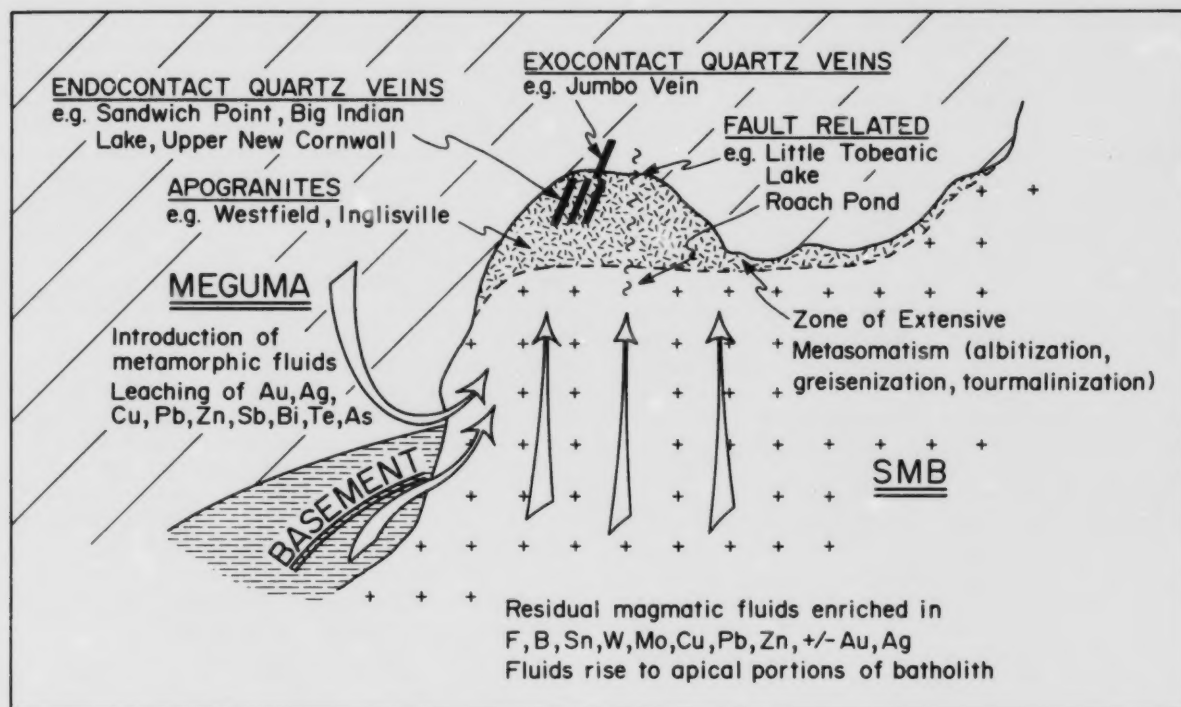


Figure 7. Model for the formation of Au enrichment in the peripheral zones of the South Mountain Batholith.

degrees of post-magmatic metasomatic alteration, within the SMB.

An integrated model involving granitic rocks, metasedimentary rocks (Meguma Group and possibly underlying basement) and the relatively impermeable granite/metasediment contact is evoked to explain most of the observed Au enrichment in the SMB.

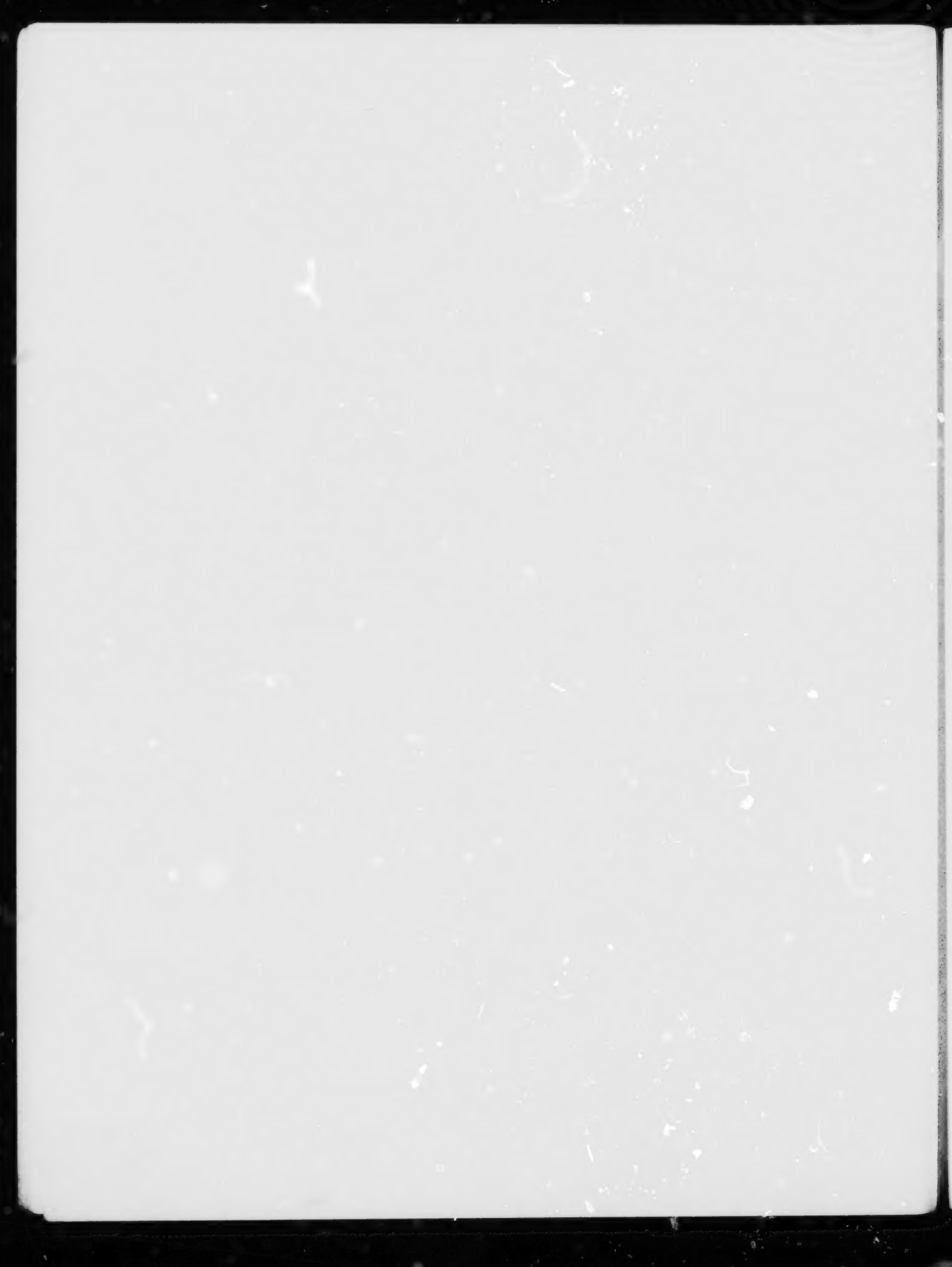
The possibility exists for an economic deposit of Au within the SMB, however, more realistically, the elevated levels of Au may increase the viability of some polymetallic Sn-W-U-Mo deposits which commonly occur in similar environments.

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POLYMETALLIC-PRECIOUS METAL POTENTIAL OF THE TOBEATIC FAULT ZONE IN SOUTHWESTERN NOVA SCOTIA

M. C. Corey and R. J. Horne

INTRODUCTION

The Tobeatic Fault Zone (TFZ) was first postulated by Giles (1985), who defined it as a major zone of sinistral shear extending from the eastern extremities of eastern Nova Scotia, westerly and southwesterly to the Yarmouth area, a distance in excess of 400 km. Recognition of the TFZ removes approximately 110 km of post-Viséan sinistral displacement allowing for realignment of structural and stratigraphic features, as well as reconfiguration of the major peraluminous granitoid bodies to form a single, large plutonic complex (Giles, 1985). Regional Bouguer gravity and airborne radiometric data support the existence of the TFZ. In addition to the obvious implications regarding granite emplacement, the TFZ has important metallogenic significance based on the occurrence of polymetallic granophile mineralization distributed along its proposed extent (Giles, 1985).

This paper describes a polymetallic mineral occurrence in the TFZ in southwestern Nova Scotia and includes the exploration case histories involved in its discovery and recent geological, geochemical and geophysical data. The precious metal potential of the study area and recommendations for future exploration along the TFZ are also addressed.

GENERAL GEOLOGY

The study area is located approximately 45 km north of Shelburne, along the southern contact of the South Mountain Batholith (SMB, Fig. 1). Recent 1:50 000 scale geological mapping (MacDonald et al., 1988; Corey and Horne, in press) show the study area to be underlain by fine- to medium-grained leucogranite (<2% biotite) and leuco-monzogranite (2-7% biotite) of the SMB and slate and metawacke of the Meguma Group (Fig. 1). The contact area between Mink and Roseway lakes is underlain by a xenolith- and biotite-rich monzogranite which may represent assimilated (granitized) metasediments.

Bedrock exposures in the study area are few and the mapping was based mostly on boulder and subcrop observations. This technique is considered to accurately reflect bedrock, based on recent till mapping and sampling (Finck et al., in press), which indicate that both granite-ablation and local

till types occur in the area. Till thickness is generally less than 3 m but local accumulations up to 6 m may occur, depending on bedrock topography.

The mapping indicates that the SMB/metasediment contact in the study area is very irregular, an observation confirmed by the results of a recent airborne gamma-ray spectrometric survey flown at 250 m line-spacing (GSC, 1988). The potassium data (Fig. 2) suggests that a large granitic body, separate from the SMB, exists between Spectacle and Tobeatic lakes, and extends south for several kilometres. Occurring within this area of elevated potassium, immediately north of the proposed trace of the TFZ, is abundant deformed (brittle/ductile) blue-grey altered leucogranite rubble. The pervasive blue-grey colouration is a phenomenon which intensifies toward the southwest within granitoids of the SMB. The cause of the colouration is unknown, but it is more common in quartz and K-feldspar megacrysts. In addition to defining probable granitic bodies, the potassium data indicate areas likely underlain by Meguma Group metasediments (areas of low potassium), suggesting that large rafts of metasediment exist within the SMB in this area.

In the area of Little Tobeatic Lake the TFZ is oriented northeast (060°) and is exposed intermittently for approximately 8 km. Surficial expression of the shear zone is manifested by milky-white quartz-breccia rubble which occurs over its entire strike length. The quartz-breccia zone appears to be less than 100 m wide, but TFZ-related effects (silicification, brittle and ductile deformation) are visible within the wall rocks up to 500 m from the quartz-breccia zone.

Most of the clasts within the quartz-breccia are comprised of angular, silicified grey metawacke and intensely kaolinized, silicified and/or hematized fine-grained leucogranite. Clasts of intensely hematized fault gouge were also observed within some quartz-breccia boulders (Plate 1). The presence of fault-gouge clasts within the quartz-breccia implies that the breccia represents a fault-breccia which was later silicified by silica-rich hydrothermal fluid which exploited the TFZ. The variety of clasts indicates that the TFZ crosscuts both rock types and is not lithologically controlled.

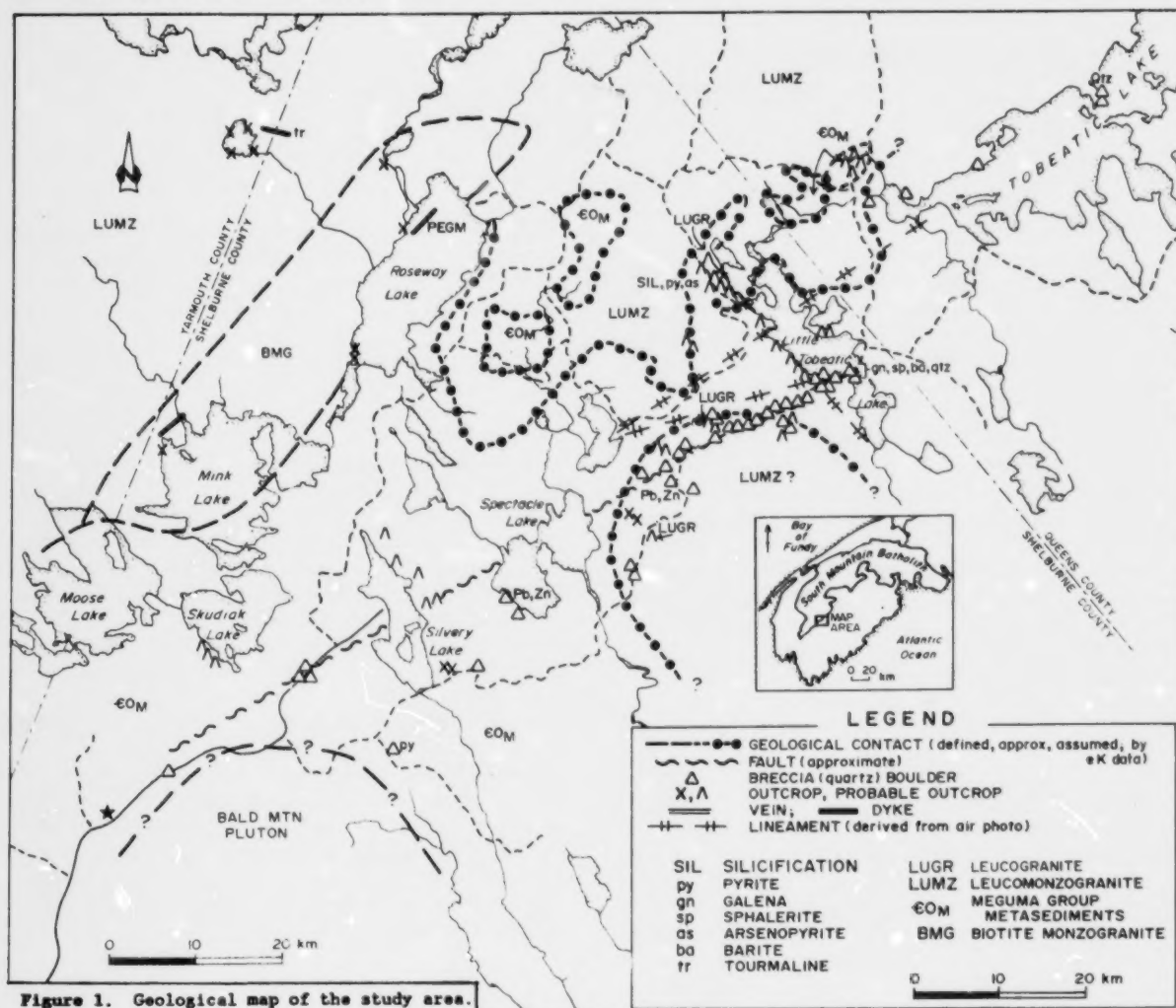


Figure 1. Geological map of the study area.

While the effects of brittle deformation are exhibited by the quartz-breccia, intense ductile deformation (mineral alignment, stretched K-feldspar megacrysts) is displayed by abundant leucogranite rubble adjacent to the TFZ (Plate 2).

This exposure of the TFZ is approximately 15 km northeast along strike of a similar shear zone in the Rushmere Lake area (Smith, 1985). Although the Rushmere Lake shear zone exhibits many of the same alteration and deformation features observed within the Little Tobeatic area, no mineralization has been documented there. Giles (1985) considered the Rushmere Lake shear zone to be part of the TFZ.

Several prominent lineaments (Figs. 1 and 3) are coincident with the TFZ in the study area and may represent related shearing. The most extensive occurrence of quartz-breccia boulders is situated at the intersection of two linears (Fig.1).

MINERAL OCCURRENCES

Mineralization in the study area consists of fine to coarse disseminations of galena $\pm$ minor sphalerite $\pm$ barite and/or chalcopyrite $\pm$ arsenopyrite $\pm$ pyrite confined to quartz-vein and quartz-breccia boulders. Barite occurs as a colloform crust infilling vugs and as large fan-shaped white crystal masses within vuggy quartz-breccia boulders (Plate 3).

The best exposed Pb-Zn-Ba mineralization is along the western shore of Little Tobeatic Lake where extensive northeast-southwest quartz veining occurs in a silicified and brecciated metawacke outcrop. At this location, disseminated chalcopyrite, pyrite, sphalerite and galena occur within quartz-breccia boulders. Approximately 200 m southwest along strike, coarse disseminations of galena, sphalerite and barite occur within extremely vuggy quartz-breccia boulders (Fig.1;

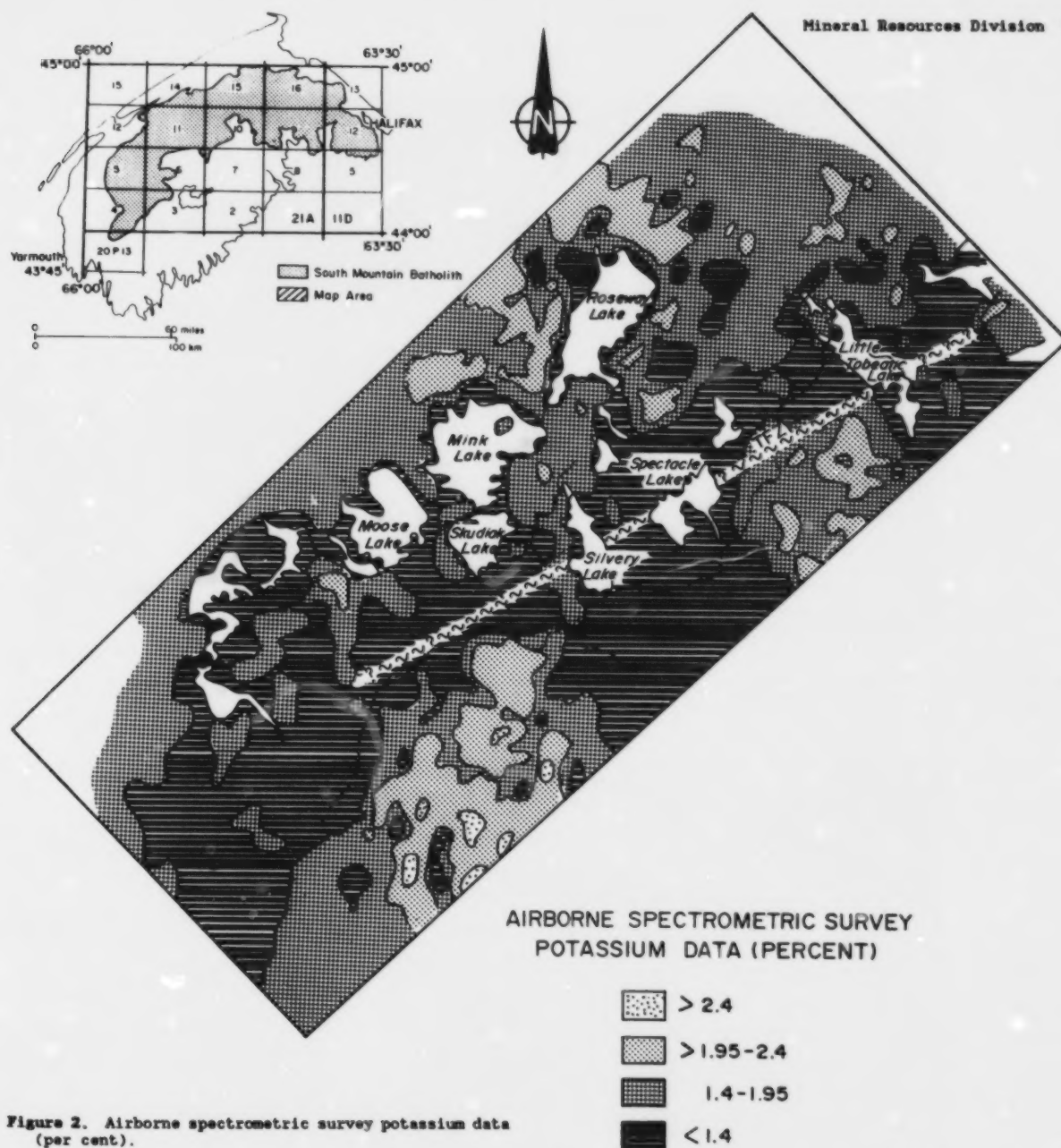


Figure 2. Airborne spectrometric survey potassium data (per cent).

Plate 4). Analysis of mineralized quartz-breccia boulder grab samples taken along the TFZ returned up to 4.9% combined Pb-Zn and 2% Ba (Dickie and Zwicker, 1983). Although the TFZ is not exposed east of Little Tobeatic Lake, the presence of Pb-Zn-bearing quartz-breccia boulders scattered along the north shore of the lake suggests that the TFZ or possibly related shearing is present.

Several analyzed samples also returned highly anomalous Au values. A sulphide-rich quartz-breccia boulder sample from south of Silvery Lake

(Fig. 3) returned up to 2035 ppb Au (Dickie, 1978) and other quartz-breccia samples in the same area returned 135 and 735 ppb Au (Fig. 3). Approximately 10 km northeast of Silvery Lake, a value of 415 ppb Au was obtained from a Pb(1.6%)-Zn(2%)-Ba-mineralized quartz-breccia boulder taken from the north shore of Tobeatic Lake (Dickie and Zwicker, 1983).

The concentrations of Au encountered in the study area are comparable to other occurrences of Au enrichment in granite proximal to the

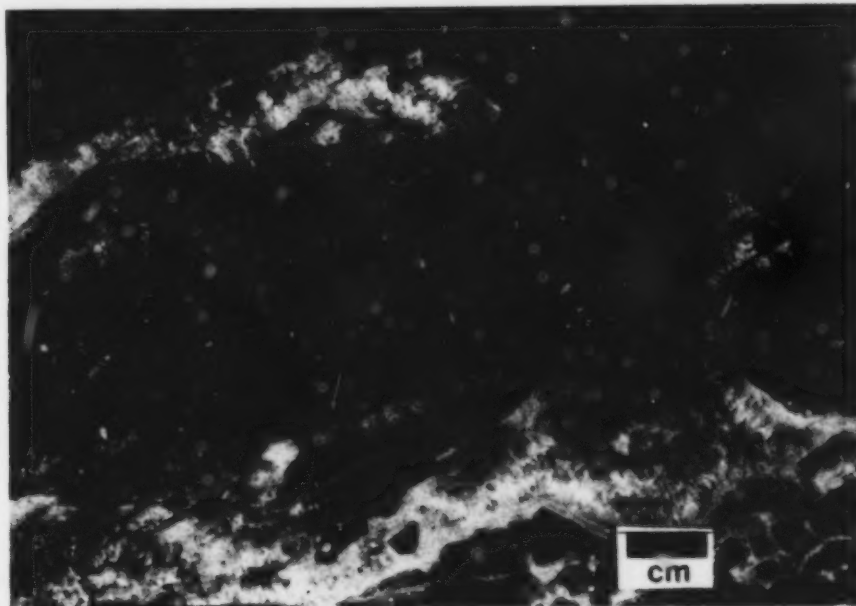


Plate 1. A quartz-breccia boulder displaying polyphase nature of quartz veins. The groundmass is comprised of silicified and hematized fault gouge.

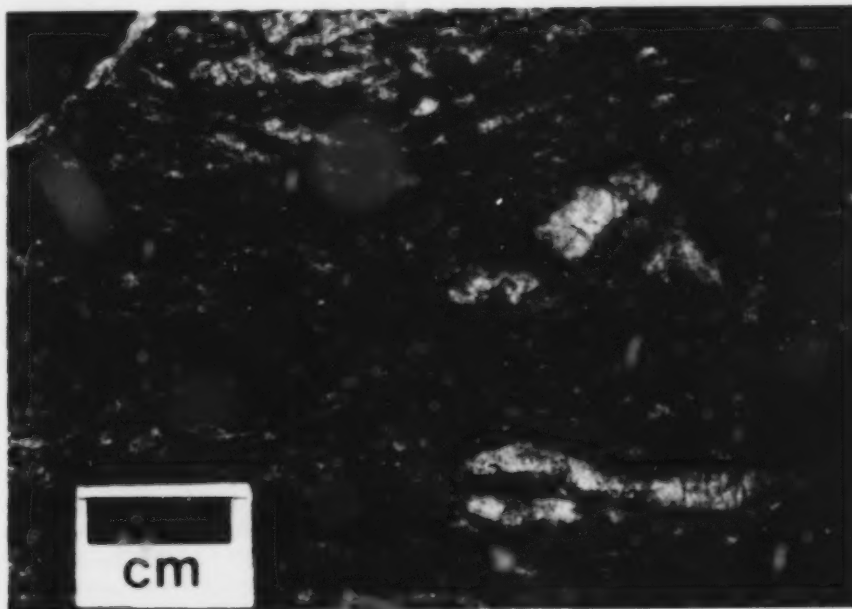


Plate 2. Intensely deformed and blue-grey altered leucogranite. Feldspar megacrysts display stretching during initial ductile deformation, and later displacement along microfractures during a period of brittle deformation. S-refers to mineral foliation; C-refers to shear fabric.

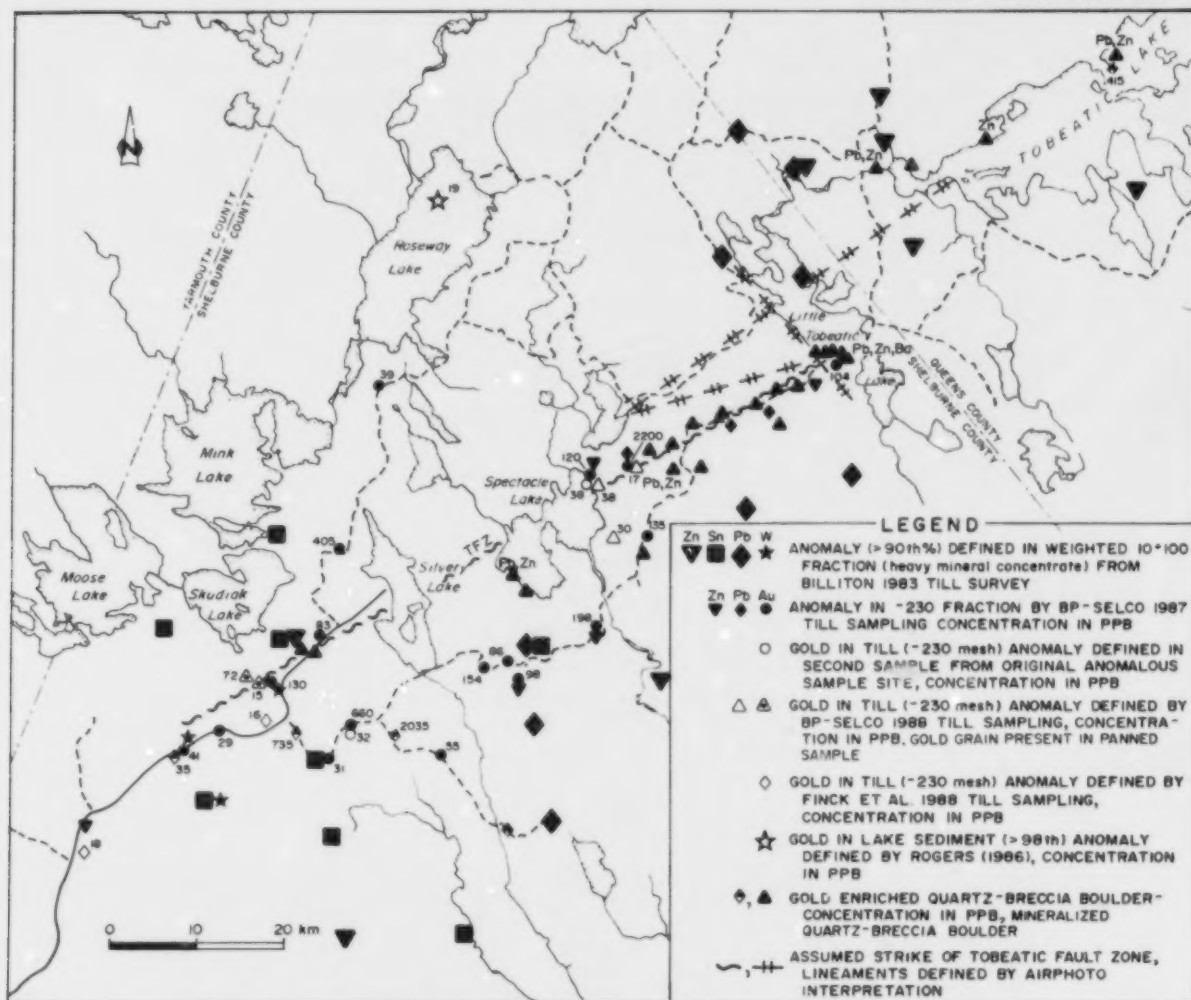


Figure 3. Geochemical compilation map of Little Tobeatic Lake area.

SMB/metasediment contact (MacDonald and O'Reilly, this volume).

EXPLORATION HISTORY AND MINERAL POTENTIAL

Extensive shearing in the study area was first delineated by Billiton Canada Ltd. in 1983 (Dickie and Zwicker, 1983). Prospecting and till geochemistry uncovered abundant Pb-Zn-Ba-mineralized quartz-breccia boulders near Little Tobeatic Lake. The area was included in a regional till (heavy mineral concentrate - HMC) sampling survey to detect 'East-Kemptville' type greisen-hosted Sn mineralization as described by Richardson (1988). For the purposes of this discussion, survey results for the study area were weighted according to Toverud (1982) and anomalies ≥ 90 th percentile were plotted (Fig. 3). The highest weighted Sn anomaly (7.5 ppm; 2595 ppm unweighted) occurs at the southern end of Mink Lake. This anomaly is highly significant

when compared to the 95th percentile weighted value of 1.05 ppm Sn within granitic till overlying the eastern SMB (Boner et al., 1987). The Sn anomalies decrease down-ice (south), implying dispersal from a point source at the southern end of Mink Lake, however, detailed prospecting by Billiton Canada Ltd. failed to uncover a bedrock source (Dickie, personal communication, 1989). The highest weighted W anomaly (4.1 ppm; 1800 ppm unweighted) occurs approximately 2 km south of Skudiak Lake and 1 km south of the TFZ. Whereas the Sn-W anomalies are confined to the west half of the study area, the Pb-Zn anomalies (HMC) are restricted to the eastern half. The highest anomalies occur 1 km south of Spectacle Lake (Pb - 25 ppm; 6680 ppm unweighted) and east of Little Tobeatic Lake (Zn - 1.8 ppm; 58 ppm unweighted). The Zn sample contained a high concentration of heavy minerals (14 g) compared to the average (3.8 g) for granitic tills overlying the SMB. This suggests that the sample originated

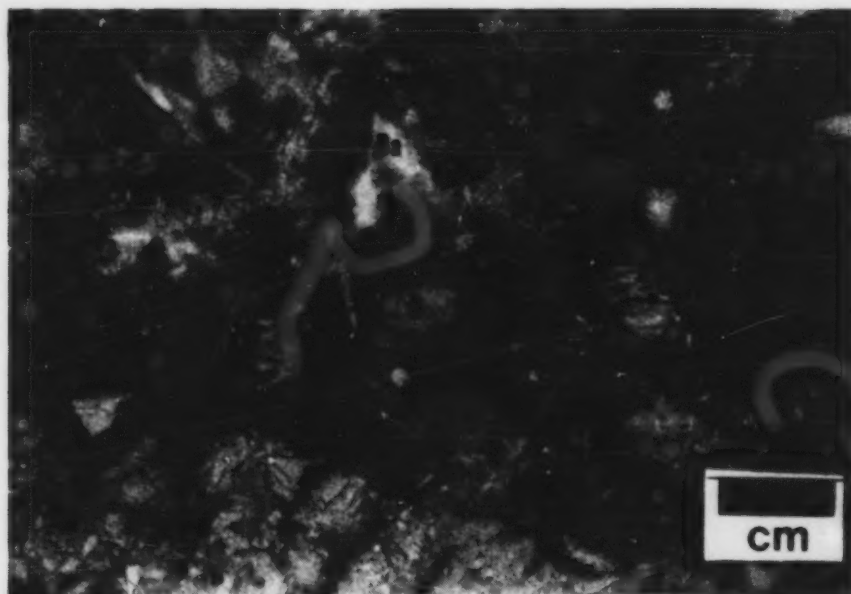


Plate 3. Close up of barite(Ba)-bearing quartz-breccia, containing silicified metawacke (Mw) and fine-grained leucogranite (G) clasts.

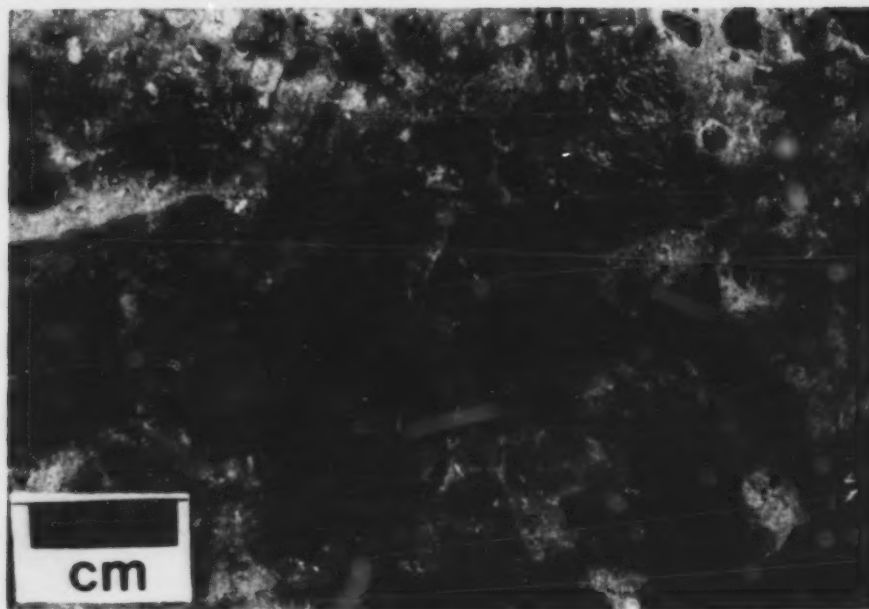


Plate 4. Quartz-breccia boulder containing coarse disseminations of galena (Gn) with minor sphalerite and barite.

from Meguma-derived till, implying that the underlying bedrock is Meguma Group metasediment (Graves, personal communication, 1989).

Subsequent to the discovery of Pb-Zn-Ba-mineralized quartz-breccia boulders, Billiton Canada Ltd. conducted line-cutting, geological mapping and an I.P.-resistivity survey along the TFZ immediately northeast of Spectacle Lake (Dickie and Zwicker, 1983). On the basis of this work, the company concluded that mineralization was not extensive in this area and their claims were allowed to expire.

Mineral exploration in the Little Tobeatic Lake area resumed in 1987 when BP Resources Canada Ltd. initiated a program to assess the gold potential of the TFZ (McKenzie, 1987). Initial work consisted of reanalysis of Billiton Canada Ltd.'s pulps using the -100 mesh fraction. The survey delineated several anomalous areas of low concentration which were not reproducible. The -100 fraction was recognized as a poor sample medium and additional till sampling was conducted, with the -230 mesh fraction analyzed for a suite of elements. This mesh fraction proved more reliable in reflecting known areas of mineralization, especially Pb-Zn-Ba mineralization associated with the TFZ west of Little Tobeatic Lake (Fig. 3).

Several areas of anomalous Au, with concentrations ranging from 30-2200 ppb, were also detected by this survey. Most of the anomalies occurred either along strike with, or down-ice from the TFZ, but several were located up-ice of the TFZ, in the area north of Silvery Lake (Fig. 3). Although reanalysis of several samples confirmed the original Au (in till) anomalies, comparable results could not be reproduced by resampling (McKenzie, 1987). This and the absence of visible Au in panned heavies led BP Resources Canada Ltd. to conclude that the samples had somehow become contaminated.

The up-ice anomalies lie within a long, narrow lobe of elevated potassium, similar in response to areas underlain by leucomonzogranite (Fig. 2). Finck et al. (in press) suggest that this area is underlain by granite-ablation till which implies an up-ice source, for the Au anomalies.

VLF-EM, magnetic and limited till sampling (-230 mesh fraction) surveys were conducted in the area by BP Resources Canada Ltd. in 1988. The geophysical surveys, conducted across the TFZ immediately east of Spectacle Lake, easily delineated the fault zone (McKenzie, 1988).

Although this till survey was successful in reproducing the results of the second round of 1987 sampling (e.g. east of Spectacle Lake - 38 ppb Au), it failed to reproduce the high Au (2200 ppb) results from the initial 1987 till sampling. The highest Au anomaly (72 ppb) from the 1988 survey occurred directly south of Skudiak Lake. BP Resources Canada Ltd. identified a single grain of Au in this sample and a nearby sample which returned 15 ppb Au. Since these samples were thought to occur up-ice of the TFZ and were comprised of slate-rich till, the company concluded that the source of the gold flakes was probably Meguma Group slate. No further work was recommended and the claims were allowed to expire.

DISCUSSION

The distribution of till (HMC, -230) anomalies and mineralized quartz-breccia boulders suggests that mineralization within the study area is zoned. The area from Silvery Lake east to Tobeatic Lake is dominated by Pb-Zn $\pm$ Ba-bearing boulders and till anomalies whereas the area west of Silvery Lake is host to Sn-W till anomalies and arsenopyrite-pyrite $\pm$ chalcopyrite-bearing quartz-breccia boulders. Whereas the source for the Pb-Zn anomalies is likely mineralized quartz-breccia associated with the TFZ, the Sn-W anomalies have no bedrock confirmation and remain unexplained. Although the area around the south end of Mink Lake is a logical source for the Sn, the possibility of multiple sources cannot be discounted.

Assuming that occurrences of Pb-Zn $\pm$ Ba-mineralized quartz-breccia boulders represent local bedrock (as suggested by field observations), approximately 8 km of the TFZ has potential for significant Pb-Zn mineralization. The presence of Pb-Zn HMC anomalies and Pb-Zn-mineralized quartz-breccia up-ice of the TFZ (e.g. north of Little Tobeatic Lake) suggests that buried mineralization may exist, possibly within associated shear zones. It may be more than a coincidence that this area is dominated by variably greisenized, pyritic leucogranite rubble.

Whereas the potential for significant Pb-Zn $\pm$ Ba and perhaps Sn $\pm$ W mineralization is well identified in the study area, the potential for Au mineralization is less conclusive. However, several pieces of evidence, listed below, suggest that additional Au exploration is warranted.

(1) Although follow-up till sampling by BP Resources Canada Ltd. failed to reproduce several of the initial high Au anomalies (2200 ppb), other Au (in till) anomalies (38 ppb) were reproduced in

successive till samples. High Mn and Fe concentrations (965 ppm) coincide with some of the highly anomalous Au (2200 ppb) in till samples, suggesting that hydromorphic concentration of Au may have occurred, creating a false anomaly. A similar association of Au with Fe and Mn was recognized in till from the Forest Hill gold district (MacEachern and Stea, 1985).

(2) Au anomalies which were repeated in successive till sampling surveys concentrate in two clusters along strike of the TFZ: south of Skudiak Lake and immediately east of Spectacle Lake. Till sampling by Finck et al. (in press) also indentified the Skudiak Lake area as the site of a Au anomaly (16 ppb, 99th percentile) within the -230 fraction. While the presence of a single flake of gold in 2 panned concentrate samples from this area should not be overemphasized, it should also not be ignored. The conclusion of BP Resources Canada Ltd. that the samples were located up-ice of the TFZ and therefore not related to it is debatable because the extent of the fault zone is not well defined in this area and there is evidence of possible related shearing north of the main silicified zone (as illustrated by Pb-Zn anomalies northwest of Little Tobeatic Lake).

The Au (in till) anomalies, which occur in a area of granite ablation till extending southwest from Roseway Lake, are interesting since Roseway Lake, is the site of a 19 ppb (99th percentile) lake sediment Au anomaly (Rogers, 1987). This suggests that the source for the Au (in till) anomalies may lie within the Roseway Lake catchment basin.

(3) Highly anomalous concentrations of Au (83-2035 ppb) in quartz-breccia boulder samples coincide with anomalous areas defined by till sampling. In most cases, anomalous multi-element (Cu-Pb-Zn-As) concentrations are associated with the Au (in till) anomalies and in the Au-enriched quartz-breccia boulders. The presence of a Au-enriched (415 ppb) Pb-Zn-mineralized quartz-breccia boulder on the north shore of Tobeatic Lake (Dickie and Zwicker, 1983) suggests that other areas of gold enrichment may exist proximal to the TFZ.

(4) The presence of high W anomalies (Fig. 3) coincident with Au (in till and rock) anomalies south of Skudiak Lake increases the attractiveness of this area due to the well-documented association of W and Au throughout the Meguma Zone (Smith, 1986).

CONCLUSIONS

A compilation of recent industry and government surveys identifies the TFZ in the Little Tobeatic Lake area as possessing significant polymetallic (Pb-Zn±Ba and Sn-W) mineral potential. The area west of Silvery Lake has Sn-W-Cu potential, whereas east of the lake, Pb-Zn-Ba mineralization predominates based upon till geochemistry and mineralized boulder occurrences. The same data suggests that potential for Pb-Zn mineralization exists along strike of the TFZ for a distance of over 8 km and that other zones of Pb-Zn mineralization occur northeast of Little Tobeatic Lake.

In addition to significant polymetallic-granophile mineralization, the TFZ (quartz-breccia) also appears to be Au-enriched. Although there are discrepancies as to the level of enrichment, particularly in the till, significant concentrations of Au in quartz-breccia boulders indicate that the TFZ in this area served as a conduit for Au-bearing fluids. The areas south of Skudiak Lake and immediately east of Spectacle Lake have been identified as having good potential for significant Au-enrichment.

A survey of detailed boulder sampling and trenching at sites of Au-enriched boulders should reveal their bedrock source. Any till sampling survey should begin with the sampling of a complete till profile to determine the size fraction in which the gold resides. The collection of panned concentrates from large samples (15-20 kg) may also prove useful when accompanied by microscopic mineral identification and analysis.

ACKNOWLEDGMENTS

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LITHOGEOCHEMICAL VARIATION WITHIN THE BIOTITE RICH ENVELOPE ROCKS OF THE EASTERN SOUTH MOUNTAIN BATHOLITH; IMPLICATIONS FOR ITS INTRUSIVE AND POST-INTRUSIVE HISTORY

R. J. Horne, M. C. Corey, L. J. Ham and M. A. MacDonald

INTRODUCTION

The South Mountain Batholith (SMB) is the focus of a regional (1:50 000 scale) mapping program by the authors. For a concise summary of the results of this survey the reader is referred to MacDonald et al. (1987, 1988). Granitoid rocks of the SMB have been divided into 8 lithologic groups: mafic porphyry, granodiorite, biotite monzogranite, muscovite-biotite monzogranite, coarse grained leucomonzogranite, fine grained leucomonzogranite, intrusive suite and leucogranite. The characteristics of each of these divisions are outlined in the above references and their distribution in the eastern portion of the SMB (ESMB) is shown in Figure 1.

Previous mapping of the SMB (McKenzie and Clarke, 1975; Smith, 1979) recognized several major "monzogranitic" (muscovite-bearing) plutons which intruded an envelope of predominantly granodiorite (biotite only). Although the 8 lithologic groups outlined above represent a petrographic-chemical continuum (principally decreasing biotite content from granodiorite to leucogranite), a similar large scale subdivision of the SMB is apparent from the authors' mapping when volumetric contribution and geographic distribution (associations of lithologic groups) of the various lithologies are considered. That is, the ESMB comprises several composite plutons of predominantly leucomonzogranite with variable amounts of leucogranite and muscovite-biotite monzogranite within an envelope of mainly granodiorite (gdio) and biotite monzogranite (bmg) with minor muscovite-biotite monzogranite (mbmg) (Fig. 1a). The feature which best distinguishes the plutons from the envelope rocks is the presence of muscovite in the lithologies associated with plutons and the lack of it in the envelope lithologies. Both the composite New Ross (NRP) and East Dalhousie (EDP) plutons (Fig. 1b) have sharp intrusive contacts with the composite envelope. In contrast, the Halifax Pluton (HP) has well defined gradational contacts with its envelope (gdio and bmg; MacDonald and Horne, 1988). The intrusive relationships have important consequences regarding batholith emplacement and will be addressed later.

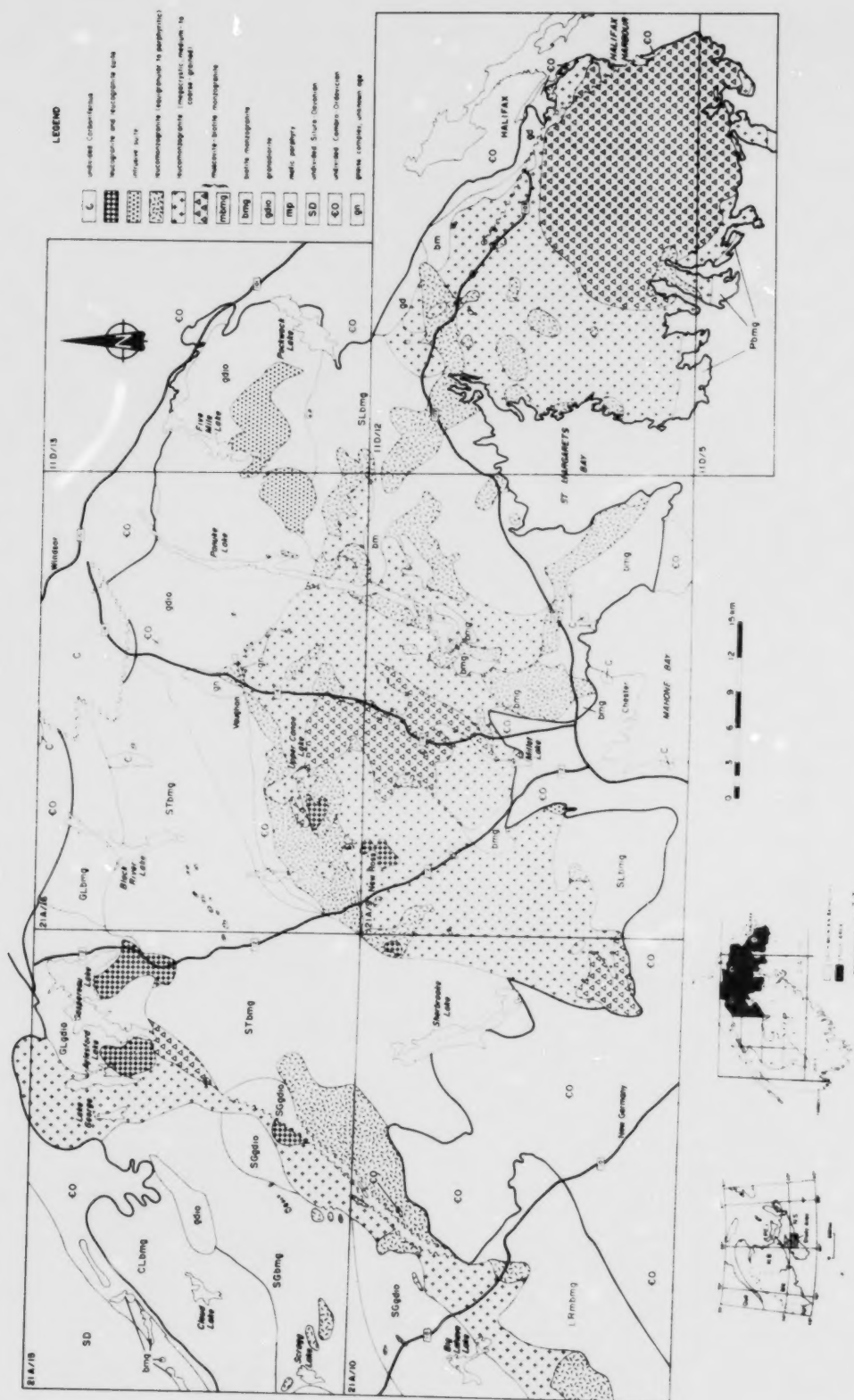
Subdivision of the envelope rocks into intrusive and/or lithologic units is often difficult. In some instances, unique and consistent textures, which generally result in consistent modal mineralogy, allow for easy subdivision; e.g. unit CLbmg in Figure 1a has a distinctive fine- to medium-grained, slightly megacrystic texture. However, the majority of the envelope generally consists of medium- to coarse-grained, megacrystic biotite granite (*sensu lato*) which ranges from monzogranite to granodiorite. Local and regional variation in texture (coarse grained megacrystic to fine- to medium-grained porphyritic) and mineralogy (i.e. 10-20% biotite; monzogranite-granodiorite) and rarity of intrusive contacts, make subdivision of these areas difficult. The problem of variable composition (i.e. granodiorite and monzogranite; Fig. 2) of the envelope rocks has been addressed in the past by referring to these areas (or units) as 'transitional granites' (McKenzie, 1974; MacDonald et al., 1986). However, in the present study, the map units indicated on Figure 1, are referred to as monzogranite or granodiorite based on average modal compositions determined by point counting stained rock slabs.

The difficulty of subdividing the envelope rocks and the resulting map patterns outlined within the envelope (Fig. 1a) makes any obvious interpretation of the intrusive nature of the batholith, as discussed by McKenzie and Clarke (1975) and Smith (1979), difficult. In addition, these patterns fail to resolve the existence of, and any possible offset along, major structural features such as the Tobeatic Fault Zone (TFZ) and East Dalhousie Fault Zone (EDFZ) (Fig. 1b).

In order to remedy the problem pertaining to the nature of the envelope rocks, the present study was designed to (1) evaluate variation (geochemical/petrographic) within the envelope rocks of the ESMB and (2) make a broad interpretation of the intrusive nature and post-intrusive history of the SMB. The following is a preliminary interpretation of the initial results of this study.

GEOCHEMISTRY

Systematic lithogeochemical sampling was



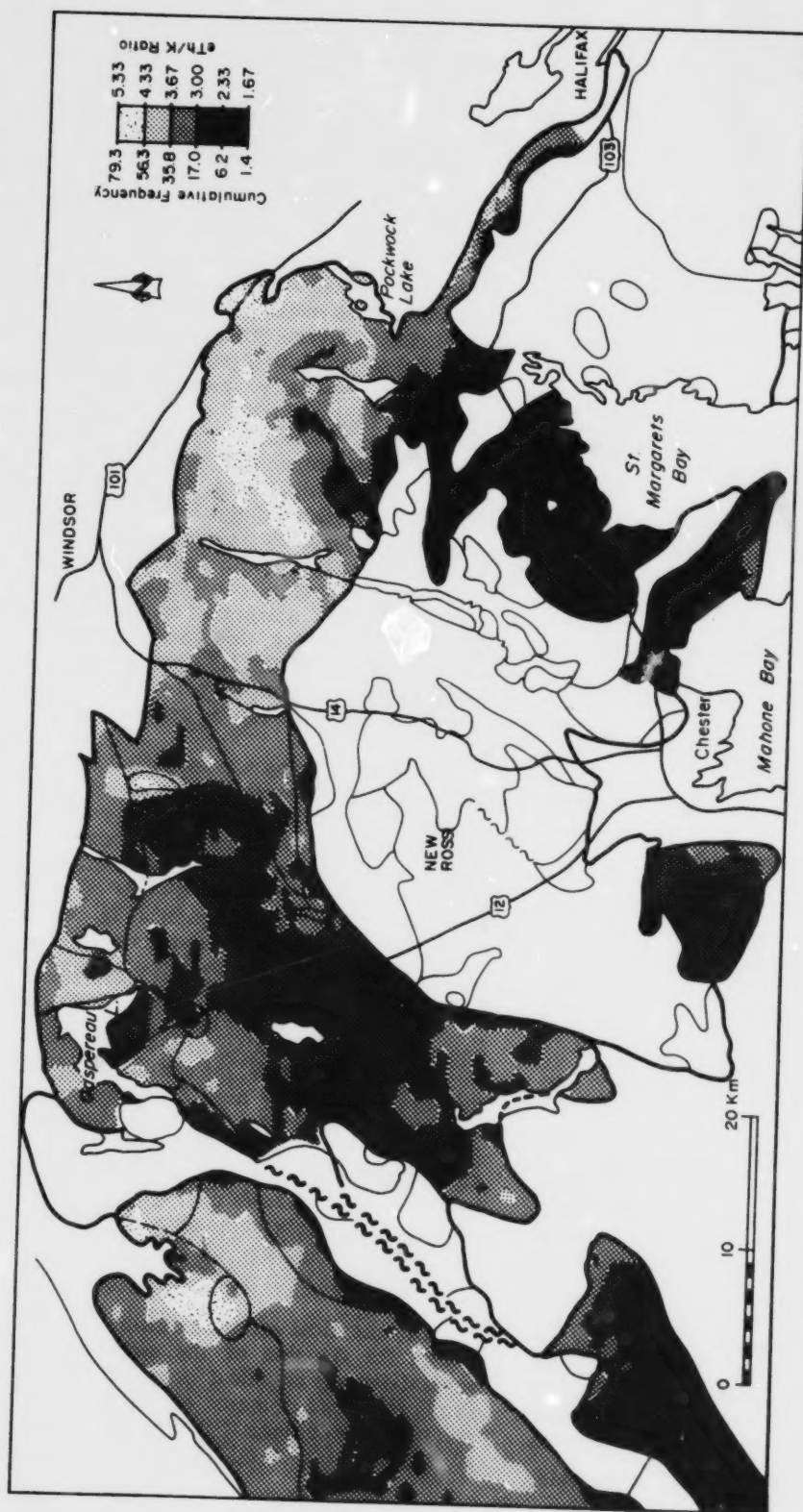


Figure 1 (b). Simplified geological map of the eastern half of the South Mountain Batholith.

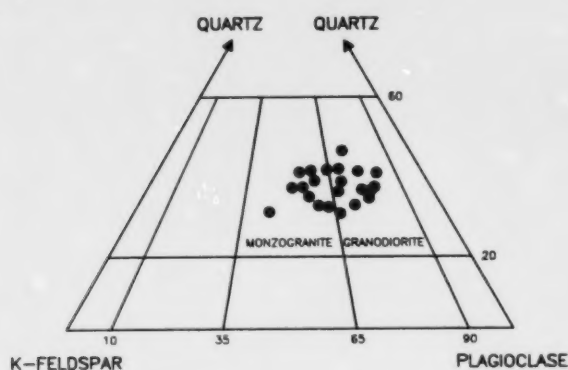


Figure 2. Ternary plot of Quartz-K-feldspar-Plagioclase for point counted samples from map unit STbm. Fields after Streckisen (1976).

conducted in conjunction with regional mapping in order to provide uniform coverage of the batholith and to assess the geochemical composition and variation of the map units. The sample distribution within the envelope rocks of the study area is shown in Figure 3. A detailed explanation of the sample collection and analytical methods is provided in MacDonald and Horne (1988).

GEOCHEMICAL RELATIONS OF MAP UNITS

Variation diagrams of Sr vs. differentiation index (DI) and (K_2O+Na_2O) vs. DI for each of the map units within the envelope of the ESMB (Fig. 1) are presented in Figure 3. Although some of these units have restricted and distinctive compositions (compare units LRmbmg and SGgdio), in general the large degree of overlap of the fields for the various units does not permit separation of the map units based solely on chemistry. For example, units STbm and gdio (Figs. 3a, c) include the chemical variation of nearly all other units. A large geochemical overlap also exists among the fields of gdio, bmg and mbmg (Figs. 3b, d). Assuming that these 3 fields define a single trend, which they appear to do, this overlap can be represented in terms of DI alone (bottom of Fig. 3b). The degree of overlap among the lithologic groups in terms of DI indicates that only in a few cases can the rocks be classified correctly using DI.

The difficulty of classification presented by the overlapping fields reflects the problems encountered in subdividing the envelope rocks into map units, i.e. the chemical variation and degree of overlap among fields translates into known petrographic variation in units (Fig. 2).

CONTOURING

In order to understand the chemical variation found in granitoid rocks, it is necessary to evaluate the variation in a geographic sense because the emplacement and subsequent crystallization (differentiation) of igneous bodies will be reflected by geographic variation of their chemistry. Therefore the differentiation index (DI) values for the envelope rocks of the study area were contoured (Fig. 4). DI values were used because they reflect several geochemical variables (e.g. normative Qz, An, Ab) and are widely accepted as indicators of the relative degree of differentiation. Contouring of several other parameters (e.g. colour index, Zr) shows similar patterns to that displayed by DI. Additionally, binary plots of several elements against DI show strong linear relationships which can be treated as differentiation trends (see below).

A detailed evaluation of the chemical variation of the HP (MacDonald and Horne, 1988) revealed a systematic variation related to a zoned pluton. The gradual petrographic and chemical variation from leucomonzogranite to biotite monzogranite to granodiorite was interpreted to represent a single intrusion. Therefore, this study includes only the northern portion of the HP (map unit SLbm; Fig. 1a) so that the relationship between the HP and the rest of the envelope can be established.

Initial contouring was modified to conform to major geological parameters such as major fault zones (EDFZ, TFZ) and intrusive contacts. This modification is considered valid because in each case incompatibilities in contouring existed between the areas on either side of these features. The area north of Vaughan (Fig. 4) was not contoured due to a lack of data and the importance of this area to the interpretation of the TFZ.

It is obvious from Figure 4 that a systematic chemical variation exists in the envelope rocks of the SMB. For example, the area north of New Ross displays consistently high DI values whereas the area west of Pockwock Lake has consistently low DI values. Some areas are systematically zoned in either a normal (relatively undifferentiated rim) or reversed sense (arrows on Fig. 4), whereas other areas are relatively homogeneous (e.g. the area in the northwest corner of the study area which corresponds to map unit CLbm).

The chemical variation outlined by contouring allows for division of the envelope rocks into several discrete chemical "domains" (Fig. 5). Major faults (between domains A and B, and B and C) and intrusive contacts (between the HP and domain A, and domains C and D) mark the boundaries of

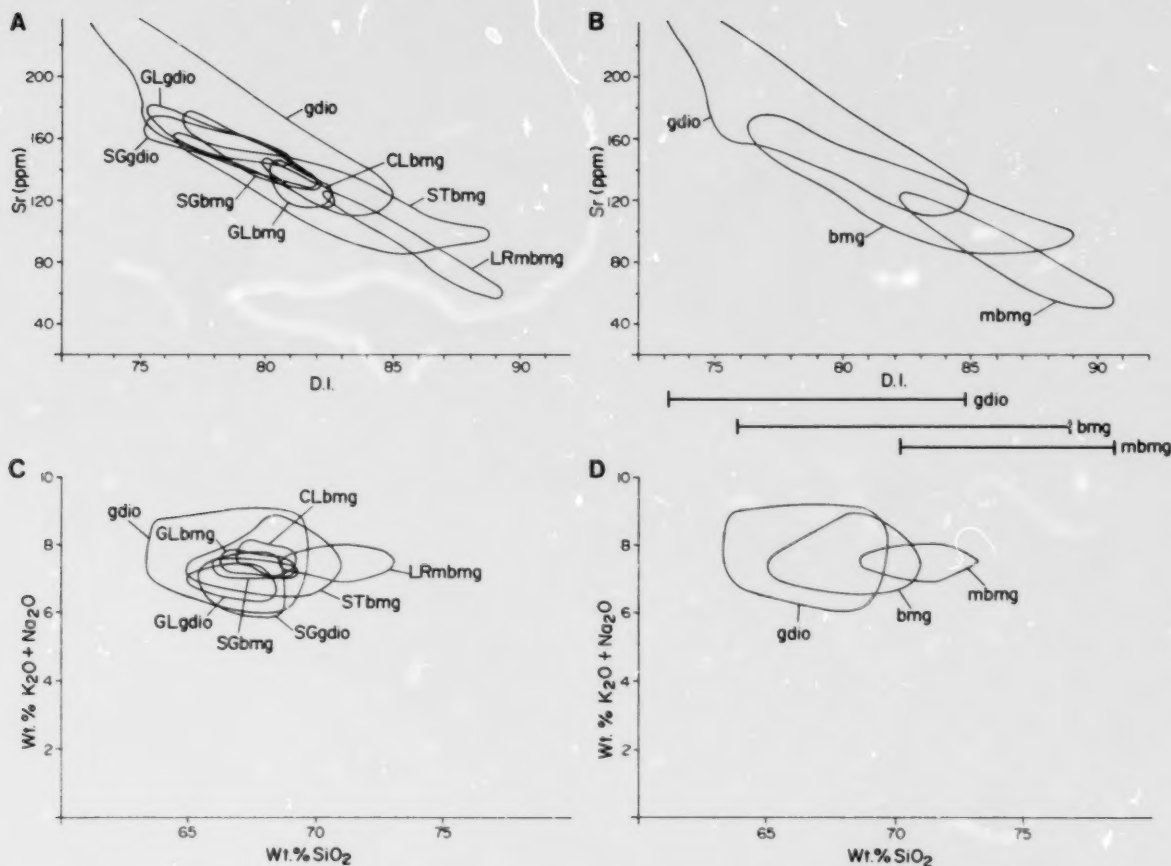


Figure 3. Variation diagrams of (a) DI versus Sr (ppm); fields represent map units, (b) same as (a) with fields representing lithologic subdivisions, (c) DI versus weight % $K_2O + Na_2O$; fields represent map units and (d) same as (c) with fields representing lithologic groups: gdio = granodiorite, bmng = biotite monzogranite, mbmg = muscovite biotite monzogranite.

these domains. The systematic within-group chemical variation of these domains suggests each domain reflects a discrete intrusion. Comparison of these domains with mapping (Fig. 1) shows a reasonable degree of correlation in most cases: areas of low DI values correspond to granodiorite and areas of higher DI values correspond to biotite monzogranite and muscovite-biotite monzogranite. What is not apparent from the map units is the systematic variation shown by contouring.

The recognition of the systematic chemical variation within the envelope rocks is significant in the interpretation of the intrusive history of the rocks and the post-intrusive history of the batholith.

In the broadest sense, the recognition of "intrusive" domains indicates the composite nature of the envelope rocks. The presence of chemical zonation within the domains allows for some

interpretation of the dynamics of intrusion and crystallization of these bodies. The recognition of features such as zoning are also important in understanding the variation, chemical and petrographic, found within map units and also highlights the inherent problems of using arbitrary classification schemes (monzogranite-granodiorite) to identify intrusive phases in areas where variation in a single intrusion straddles arbitrary fields.

The recognition of intrusive bodies, such as domains, and patterns related to intrusion within these bodies allows for objective interpretation of the presence of, and possible offset along, faults in the batholith. This is evident in Figures 4 and 5 where the presence of the EDFZ and TFZ accounts for abrupt changes in chemical variation.

O'Reilly et al. (1988) demonstrated a strong correlation between airborne radiometrics, in

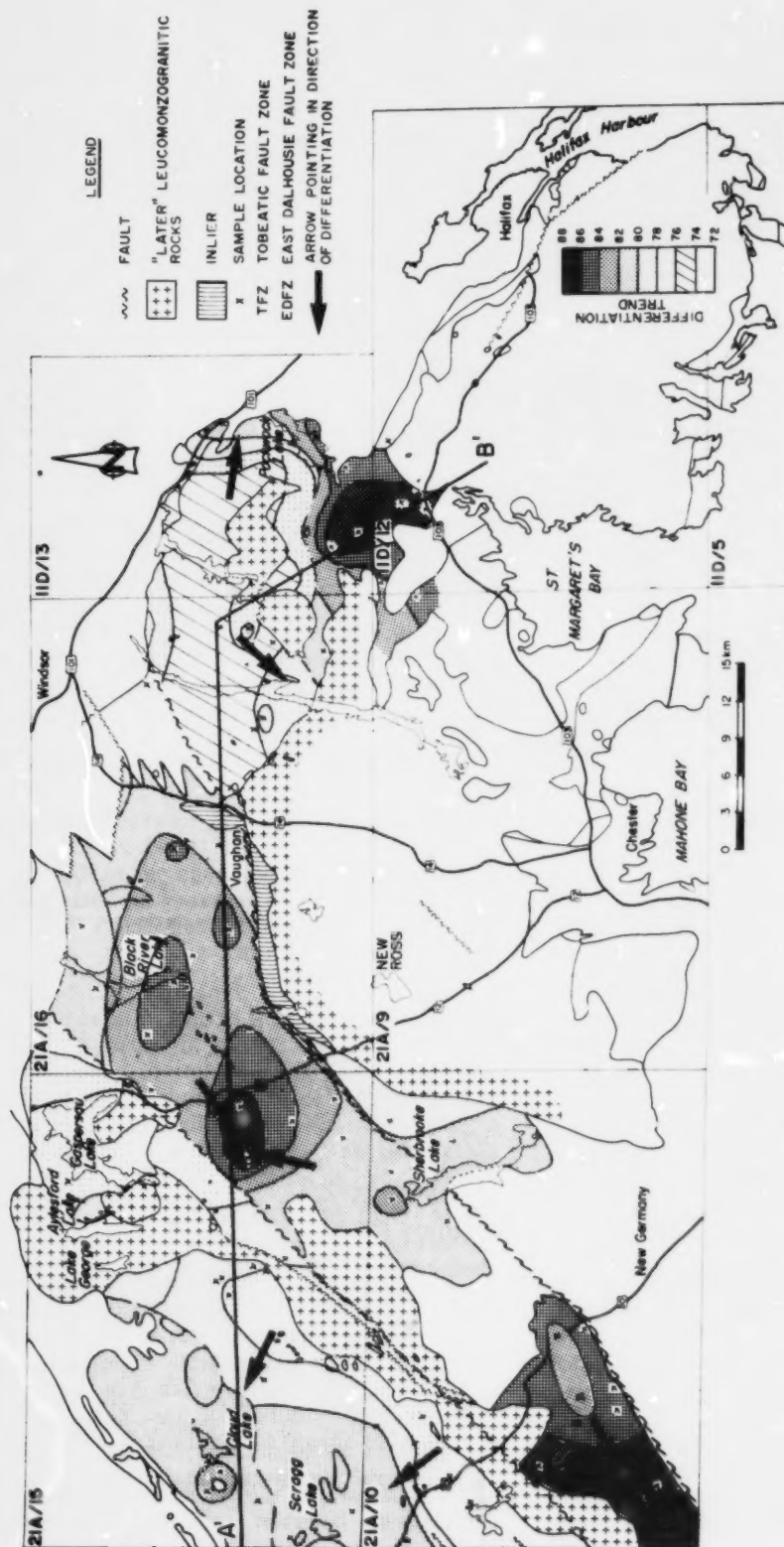


Figure 4. Map of contoured differentiation index values for the envelope rocks of the eastern half of the South Mountain Batholith (for cross-section along A'-B', see Figure 1).

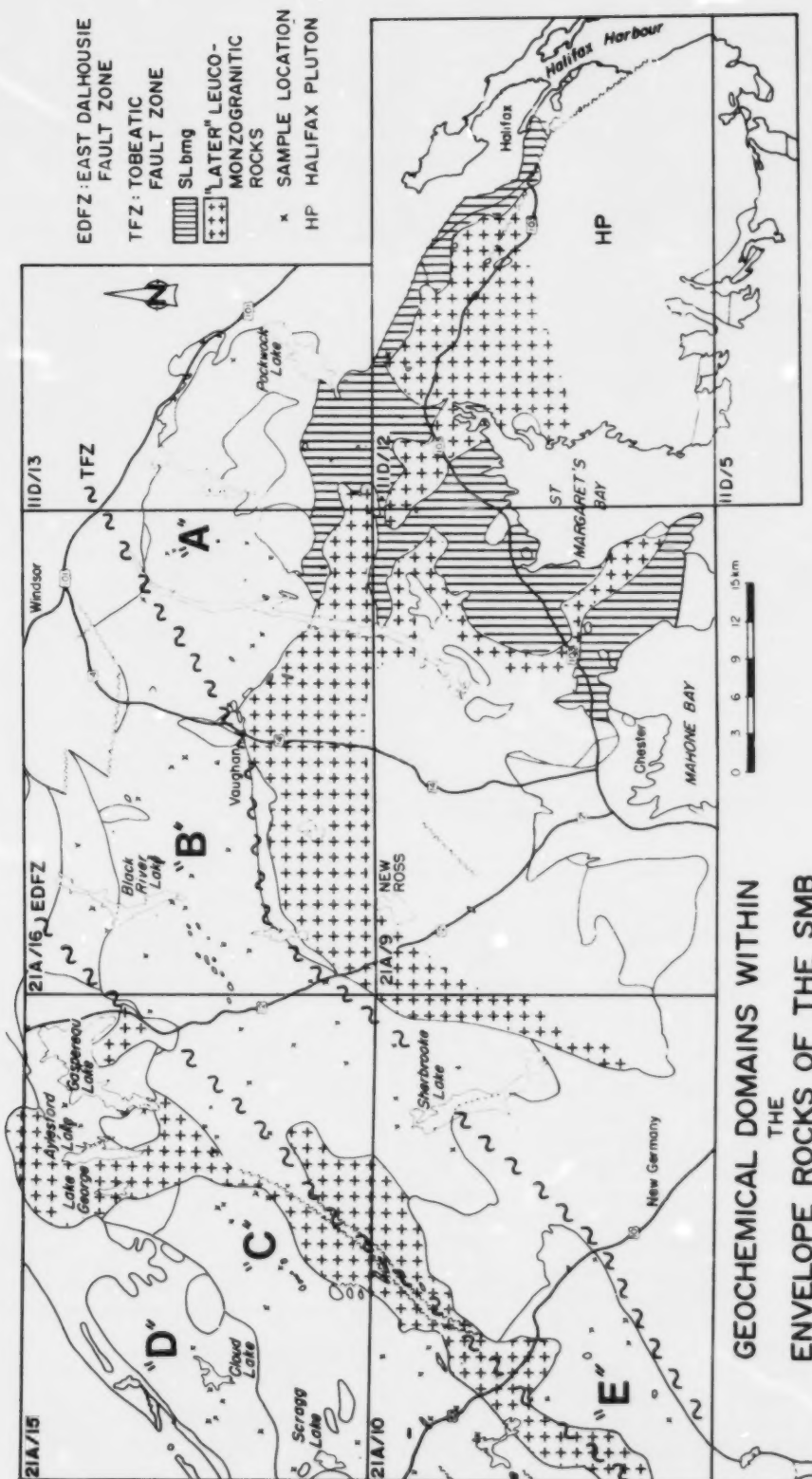


Figure 5. Map showing geochemical domains in the envelope rocks of the South Mountain Batholith.

particular equivalent uranium/equivalent thorium values, and bedrock geology for parts of the SMB. This was interpreted to be a reflection of varying lithochemical trends related to differentiation and, to some degree, modification of lithochemistry due to hydrothermal activity. The latter suggested to have occurred predominantly within leucomonzogranites and leucogranites. A comparison of the contoured DI values (Fig. 4) with airborne radiometrics in the study area (Fig. 6) indicates a good degree of

mineralogy of the samples, determined from point counting (Fig. 8). The variation within and among domains, however, can be explained in terms of systematic geographic variation as seen in the contouring. The large variation shown by domain B reflects a large range of chemical zonation (Fig. 3), whereas the restricted variation of domain D reflects a chemically homogeneous body.

Collectively, and individually, the chemical variation of all groups (domains) defines a single

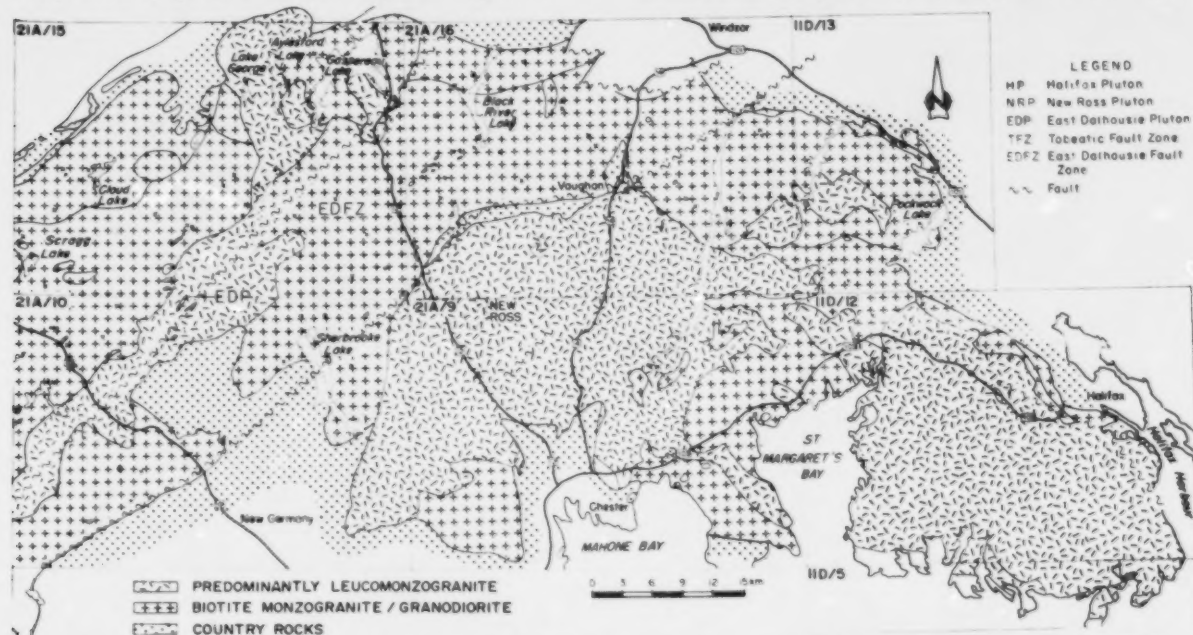


Figure 6. Equivalent thorium/potassium ratio map of southern Nova Scotia; modified after Ford et al., in press.

correlation. The level of sensitivity of the airborne response can be evaluated in the area between the TFZ and EDFZ (domain B) where the zoning reflected by contoured DI is crudely reproduced by the airborne radiometrics. In this area a core of relatively low eTh/K values (more differentiated) is surrounded by a rim of higher eTh/K values (less differentiated). However, the correlation does not always hold; for instance, the radiometric response for domains A and D are virtually identical, but DI values for these areas are quite different.

GEOCHEMICAL RELATIONS OF DOMAINS

Binary diagrams of selected variables for each of the domains are presented in Figure 7 using the same samples presented in Figure 3, however, new fields are defined. As was found in the case of both map units and lithologic groups, large overlaps exist among the fields of the various domains. The overlap is also apparent in the modal

smooth trend, consistent with the trend defined by all geochemical samples of the batholith. The chemical variation of the envelope rocks alone accounts for most of the variation seen in the batholith (Fig. 7). Although not presented here, variation diagrams of all the major oxides and trace elements against SiO_2 display similar singular trends. Several authors (McKenzie and Clarke, 1975; Smith, 1979; MacDonald and Horne, 1988; Kontak et al., 1988) concluded that these chemical trends can be explained by fractional crystallization. Although this argument has been extended to suggest that the entire SMB is comagmatic (McKenzie and Clarke, 1975), Kontak et al. (1988) suggest that, at face value, singular trends only indicate that broadly comparable processes have been operative throughout the SMB.

DISCRIMINANT FUNCTION ANALYSIS

Richard (1988) points out that in recent years there has been increasing concern about the validity of

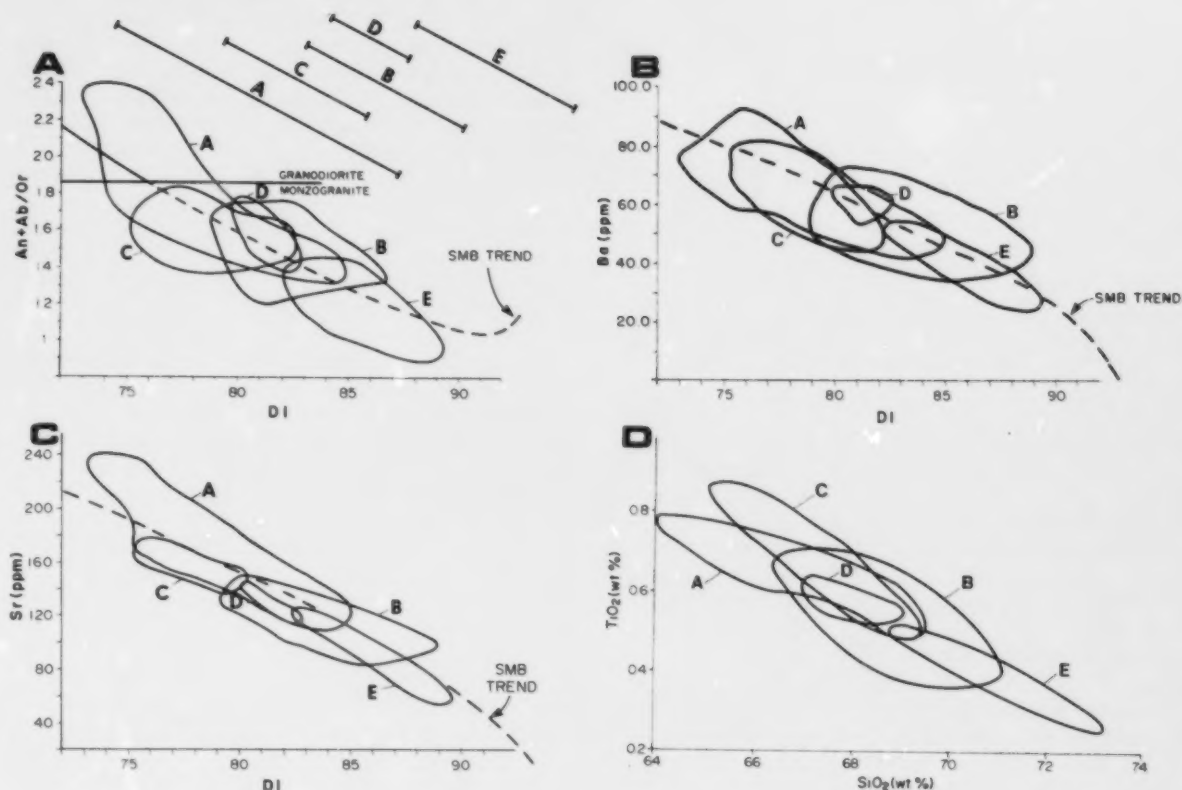


Figure 7. Variation diagrams for (a) normative anorthosite + albite/orthoclase vs. DI, (b) Ba vs. DI, (c) Sr vs. DI and (d) TiO_2 vs. SiO_2 . Fields A to E represent the domains of Figure 3.

petrogenetic interpretation based on the correlation of only one or two variables. This is due to the closed nature of geochemical data sets such that variation in one variable causes variation in other variables. The above interpretation of the geochemical trends for the ESMB data set is subject to this problem. In light of this, discriminant function analysis (DFA), a multivariate statistical technique, was applied to the data to test the chemical similarity of the domains. DFA tests the degree of divergence between specified data sets (domains in this case), thereby examining the possibility that each (or some) of the domains represent distinct geochemical populations which could not be explained simply by progressive fractionation. The computer program SYSTAT (Wilkinson, 1986) was used.

Several prerequisite conditions for statistical validity when applying DFA have been discussed by Richard (1988):

(1) The number of samples must be at least 3 times greater than the number of variables used

(note, some workers suggest a ratio of 10:1). This eliminated domains D and E, with only 6 and 8 samples, which would allow for the use of only 2 variables.

(2) The problem of closure must be eliminated. This was done by dividing each variable by the value of SiO_2 for that sample.

(3) The data should be normally distributed. To approach this condition, logarithmic values were used.

An additional problem with statistical evaluation of multi-element geochemical data sets is reduction of a large number of variables (elements) to a number which will satisfy the first condition above (in this case five). An inherent problem in achieving this end is that you must either (1) break the condition you are attempting to achieve by applying DFA with too many variables and progressively eliminating the least discriminating variables, or (2) break the data set into a number of subsets so that condition 1 is more closely approached, and use the best discriminators from each subset. The obvious

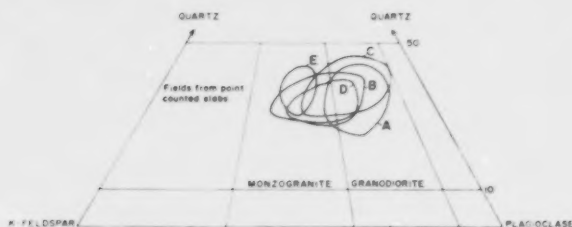


Figure 8. Quartz-K-feldspar-Plagioclase ternary diagram for envelope rocks of the eastern half of the SMB. The groups represent the geochemical domains in Figure 5 (fields after Streckisen, 1976).

problem is that the best discriminators are relative to the elements in the subset, and may not be good discriminators for the data set as a whole. Although many possible methods can be used to reduce the number of variables to a number which will satisfy condition 1, the following procedure was used in this study. The initial 29 variables were first divided into 3 sets of variables (with 10, 10 and 9 variables) by selecting the first 10 elements, second 10 elements, etc. from a prearranged sequence of major and trace elements, i.e. no bias was used in selecting the elements in each group. Each set was subjected to DFA and the 3 best discriminating variables from each of these runs were used to form another subset. This subset was then subjected to DFA. The 5 best discriminating variables from this run were run through DFA again and produced the resulting discriminant function: $F1 = -0.003 \text{ Fe}_2\text{O}_3 - 2.712 \text{ TiO}_2 + 1.491 \text{ Zr} + 0.473 \text{ Y} + 0.510 \text{ Hf}$, $F2 = 0.418 \text{ Fe}_2\text{O}_3 - 0.466 \text{ TiO}_2 - 0.210 \text{ Zr} + 0.845 \text{ Y} + 0.471 \text{ Hf}$. The "best discriminators" in each case were chosen by weighting the standardized canonical coefficients of each function by the coinciding eigenvalue (measurement of significance) of each function and choosing the strongest pairs.

The results (Fig. 9) indicate a significant degree of separation between the three groups (domains), i.e. each group forms its own distinct population. This is most readily apparent by assessing the percent classified for each domain, which is the percentage of samples from that group which were ascribed to that group as opposed to either of the other groups.

The elements which best discriminated the data (TiO_2 , Zr, Hf, Y, and Fe_2O_3) mainly reflect the presence of biotite and zircon, a common inclusion in biotite. A plot of colour index (CI), which for these rocks can be considered to vary directly with the proportion of biotite, vs. DI (Fig. 10), considered a measure of the degree of

differentiation, indicates that the percentage of biotite is strongly proportional to the degree of differentiation. Given this, and the large overlap in CI that exists among the 3 domains (Fig. 10), the discrimination found among the various domains cannot be attributed to varying amounts of biotite. In fact, DFA suggests that the discrimination is caused by variation in the combined mineral chemistry of biotite + zircon. In contrast, the lack of discrimination of major and trace elements associated with the feldspars (i.e. Ca, K, Na, Ba, Sr, Rb) suggests that their chemistry more closely reflects differentiation trends.

Possible explanations for variable mineral chemistries between biotite and zircon for different domains are numerous. Some of the mechanisms which might give rise to this include: (1) variable source regions (through either elemental contribution to the melt or inclusion of restite phases); (2) variable degrees of contamination from enclaves; (3) different physio-chemical conditions (e.g. f_{O_2} , $\text{P}_{\text{H}_2\text{O}}$) and fractionation processes and (4) various combinations of one or more of the aforementioned factors. Kontak (personal communication, 1989) has noted the presence of 2 petrographically distinct biotites (inclusion poor and inclusion rich) within the SMB and suggests that one of these may be restite, varying proportions of which may account for the chemical discrimination described above. Considerable petrographic and mineral chemical data are required to adequately assess this hypothesis.

DISCUSSION

This study has revealed previously unrecognized chemical (petrographic) variation in the envelope rocks of the ESMB. The patterns exhibited by this variation are interpreted to reflect physical and chemical features of these rocks and as such outline several intrusive 'domains'. Recognition of these domains permits several broad conclusions to be made with regard to the intrusive history of the ESMB as well as subsequent faulting.

The regional scale nature of the batholith can be interpreted. The ESMB can be considered, in general, to comprise a series of predominantly leucomonzogranitic plutons within an envelope of bmg and gdio. In an intrusive sense, however, the bmg and gdio associated with the HP is inherently different than that in the rest of the batholith in that it is chemically and petrographically gradational with the leucomonzogranite of the HP. In this regard, the bmg and gdio associated with the HP are not true envelope rocks. This gradational effect with the envelope rocks is

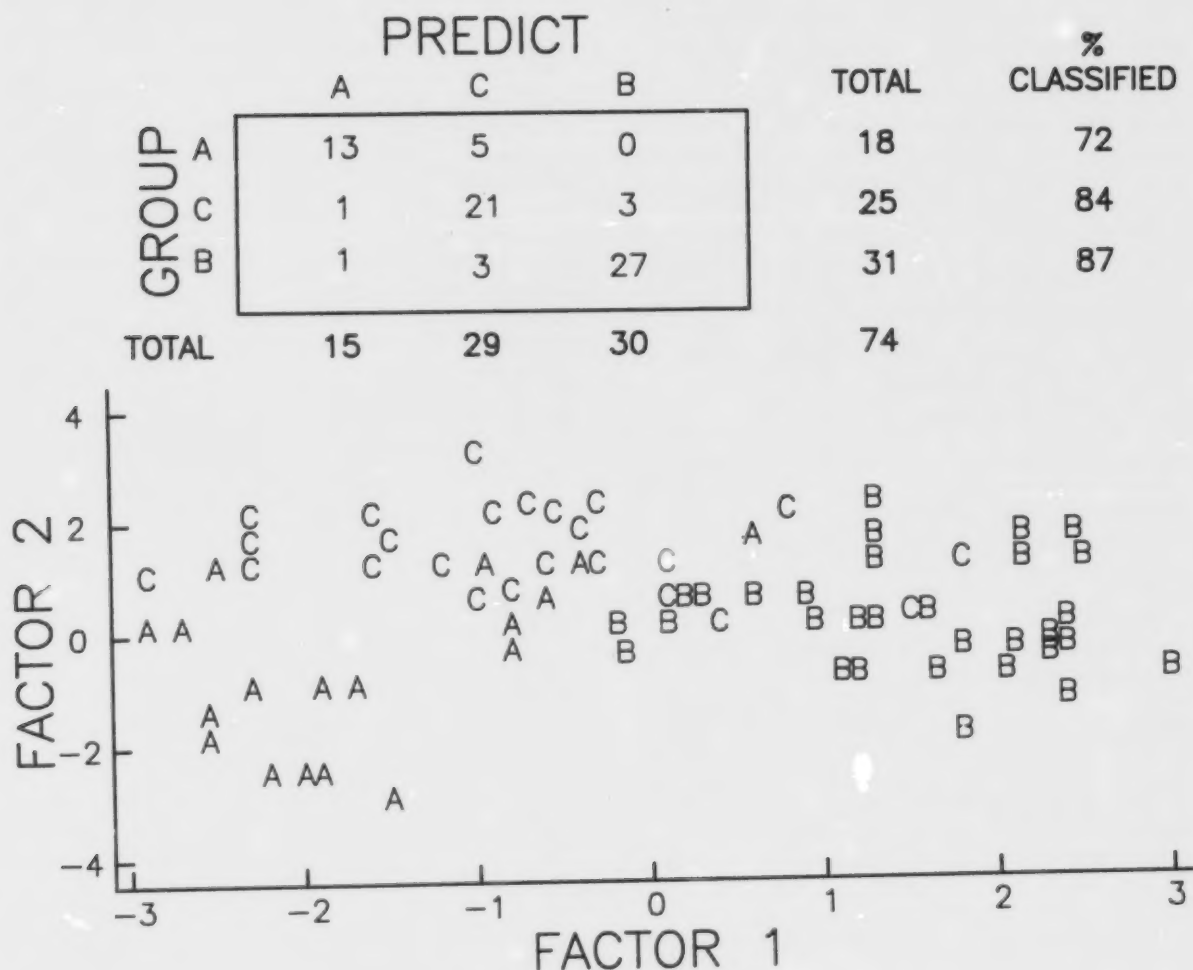


Figure 9. Results of discriminant function analysis among (a) domains A, B and C and (b) domains A, B, C, D and E.

restricted to map unit SLbmg, which is chemically distinct from domain A. Both sharp intrusive and gradational contacts have been observed between SLbmg and domain A.

Chemical variation in the envelope rocks of the remainder of the ESMB indicates that it consists of a number of distinct intrusions (domains) each of which reveals chemical, and presumably petrographic, features reflecting separate intrusive and crystallization histories. These domains show no apparent relationship with spatially associated composite leucomonzogranite plutons (i.e. NRP and EDP). In fact, both the NRP and EDP cut discordantly across more than one of the domains. As was the case with the HP and domain A, the intrusive relationships among the different domains are unclear. Both sharp and gradational contacts

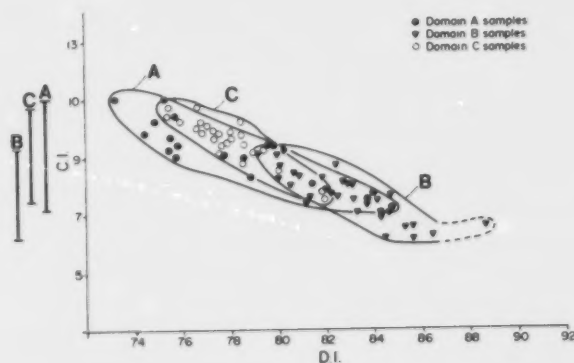


Figure 10. Variation diagram of colour index (CI) against DI for domains A, B and C.

between units are common in the batholith (MacDonald et al., 1987) which suggests relatively simultaneous intrusion of all units.

Singular chemical covariation trends among the various domains within the envelope rocks suggest that the exposed variation (contour patterns) can be explained simply in terms of various levels of exposure of different intrusions which are chemically related (Fig. 11). Mechanisms to explain features such as normal and reversed zoning would be necessary to present a complete model.

simultaneously. This near simultaneous intrusion is supported by isotopic dating (Clarke and Halliday, 1980; Reynolds et al., 1981). It is therefore reasonable to assume that the SMB resulted from a single magma-generating event, and that physio-chemical conditions were probably similar for presently exposed rocks, especially for the restricted compositional range considered here. The chemical discrimination among domains is not related to contamination, as such contamination would be expected to reflect regional variation in country rocks. Therefore, slight variation in the source region may be the most likely cause for the chemical differences.

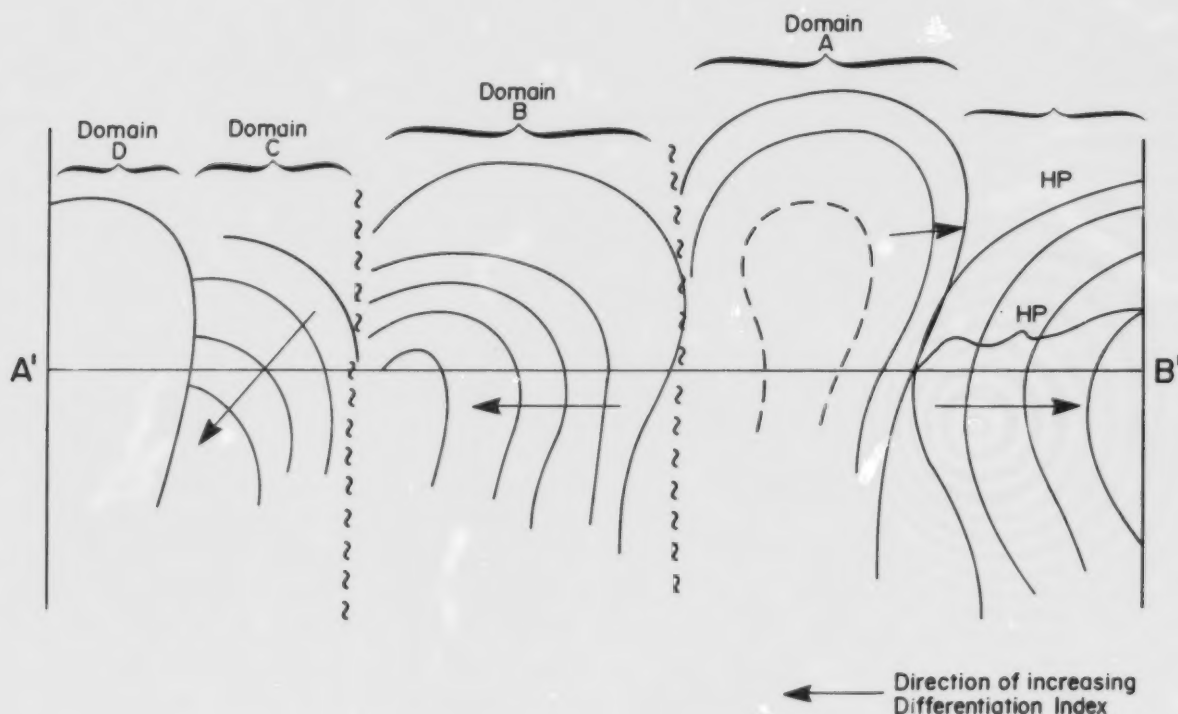


Figure 11. Schematic cross-section through the domains within the envelope rocks and the HP (location of line A'-B' is shown on Figure 3) explaining the observed chemical variation and relationship between the various intrusive bodies. HP = Halifax Pluton, A, B, C, D, E = domains as in Figure 3, TFZ = Tobatic Fault Zone, EDFZ = East Dalhousie Fault Zone.

The results of discriminant function analysis indicate chemical differences among some of the domains within the envelope rocks which are apparently due to variation in mineral chemistries of biotite and zircon. Although the full cause(s) of this discrimination is not well understood, certain restrictions may be suggested from field evidence. The presence of both sharp and gradational contacts and the lack of significant chilled margins suggests that the domains comprising the envelope were intruded nearly

The recognition of intrusive features is important with regard to the interpretation of major fault patterns within intrusive rocks. In the SMB the location of the TFZ and possible offset along the EDFZ were not apparent from mapping. However, the recognition and interpretation of systematic chemical variation permits quantitative interpretation of major faults. For instance, major chemical discrepancies between domains A and B can be interpreted to reflect the proposed trace of the TFZ (Giles, 1985). As well, the trace of the

EDFZ is projected to the north from its previously known extent (MacDonald et al., 1988) to explain chemical variation between domains B and C. The geochemical quantification of the difference of the rocks on either side of the EDFZ and the apparent crosscutting of chemical contours by the EDFZ (Fig. 3) implies significant displacement has occurred along this structure.

ACKNOWLEDGMENTS

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THE GRAPHITE-BEARING, KEMPT SNARE LAKE GREISENIZED LEUCOGRANITE CUPOLA, YARMOUTH COUNTY, NOVA SCOTIA¹

T. P. Soehl², G. A. O'Reilly, D. B. Clarke² and P. H. Reynolds²

ABSTRACT

At Kempt Snare Lake, Yarmouth County, a leucogranite-leucomonzogranite cupola hosts quartz veins containing W-Zn-Pb-As-Cu-Ag mineralization. The fluid that formed the veins and associated hydrothermal alteration was rich in K, CO₂ and F and migrated along the northeast-trending East Kemptville shear zone (EKSZ). Continued shearing along the EKSZ affected the cupola after hydrothermal alteration ceased. Age dating of 2 muscovites and a K-feldspar by ⁴⁰Ar/³⁹Ar gives the minimum age of intrusion of the cupola as 330 Ma. Deformation of the micas continued to a minimum of 265 Ma ago with a peak at ≈300 Ma. The K-feldspar date reflects a thermal event at 220 Ma ago.

Hydrothermal graphite pervaded the cupola during the hydrothermal event. The graphite may be the result of reduction of CO₂ from the magmatically derived fluid, or may have been inherited from enclosing pelitic metasedimentary rocks rich in carbonaceous detritus.

Whole-rock geochemistry shows the progression of alteration is marked by increase of K₂O, Al₂O₃, H₂O⁺, Rb and C and decrease of SiO₂, Na₂O, CaO and Sr. These chemical trends reflect: (1) destruction of the major primary minerals; (2) the potassic nature of the hydrothermal fluid; (3) abundance of secondary muscovite; and (4) influx of hydrothermal graphite. The levels of U and Th in the cupola are comparable to those in the nearby Davis Lake Pluton of the South Mountain Batholith suggesting a genetic link between the 2 intrusions.

INTRODUCTION

The Kempt Snare Lake (KSL) greisenized leucogranite-leucomonzogranite body at the southwest end of Kempt Snare Lake, Yarmouth County hosts W-Pb-Zn-As-Cu-Ag mineralization (Fig. 1). The KSL body occurs along a linear belt of granite- and metasediment-hosted deposits of granophile elements and base metals that extends for 30 km from within the South Mountain

Batholith (SMB) in the northeast to the Atlantic coast at Wedgeport in the southwest. This linear belt of deposits was first recognized by Chatterjee (1983) who referred to it as a polymetallic tin domain. More recent investigations (Kontak, 1987; O'Reilly, 1988) have shown that several of these deposits are spatially associated with shearing along the regional northeast-trending East Kemptville shear zone (EKSZ; Fig. 1).

The KSL body is hosted within Cambro-Ordovician Meguma Group metasediments approximately 4 km from the western extremity of the SMB. Its contact with the metasediments is nowhere exposed, so whether it is intrusive or fault bounded cannot be confirmed. The wedge shape of an IP geophysical anomaly coincident with the body and the widespread evidence of shearing and faulting suggests its emplacement along faults is possible. Its small size and proximity to the SMB suggest that it is probably intrusive and it will be referred to as the Kempt Snare Lake cupola (KSLC) in this paper.

The largest deposit in the EKSZ, the greisen-hosted East Kemptville tin deposit, has received much attention since its discovery in the late 1970s. Some of the other deposits, although smaller, warrant further examination and documentation. A program of 3 diamond-drill holes on the KSLC was carried out by Falconbridge Limited in 1986 (Jensen, 1987). Access to the drill core, granted by Falconbridge, provided an opportunity to examine the geological and geochemical features of the cupola and interpret its position in the geological setting of southwest Nova Scotia.

EXPLORATION HISTORY

Galena- and sphalerite-bearing quartz and "black granite" boulders were discovered in the Kempt Snare Lake area in 1927 (Jensen, 1987). The following year, after trenching, a vertical shaft was sunk to a depth of 23 m on a 2 m wide quartz vein. Grades of 2% combined Pb-Zn, 0.5% Cu and up to 61 ppm Au and 153 ppm Ag were reported by Grant (1948). Jensen (1987) reported similar Pb-

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² Department of Geology, Dalhousie University, Halifax, Nova Scotia, B3J 3H5

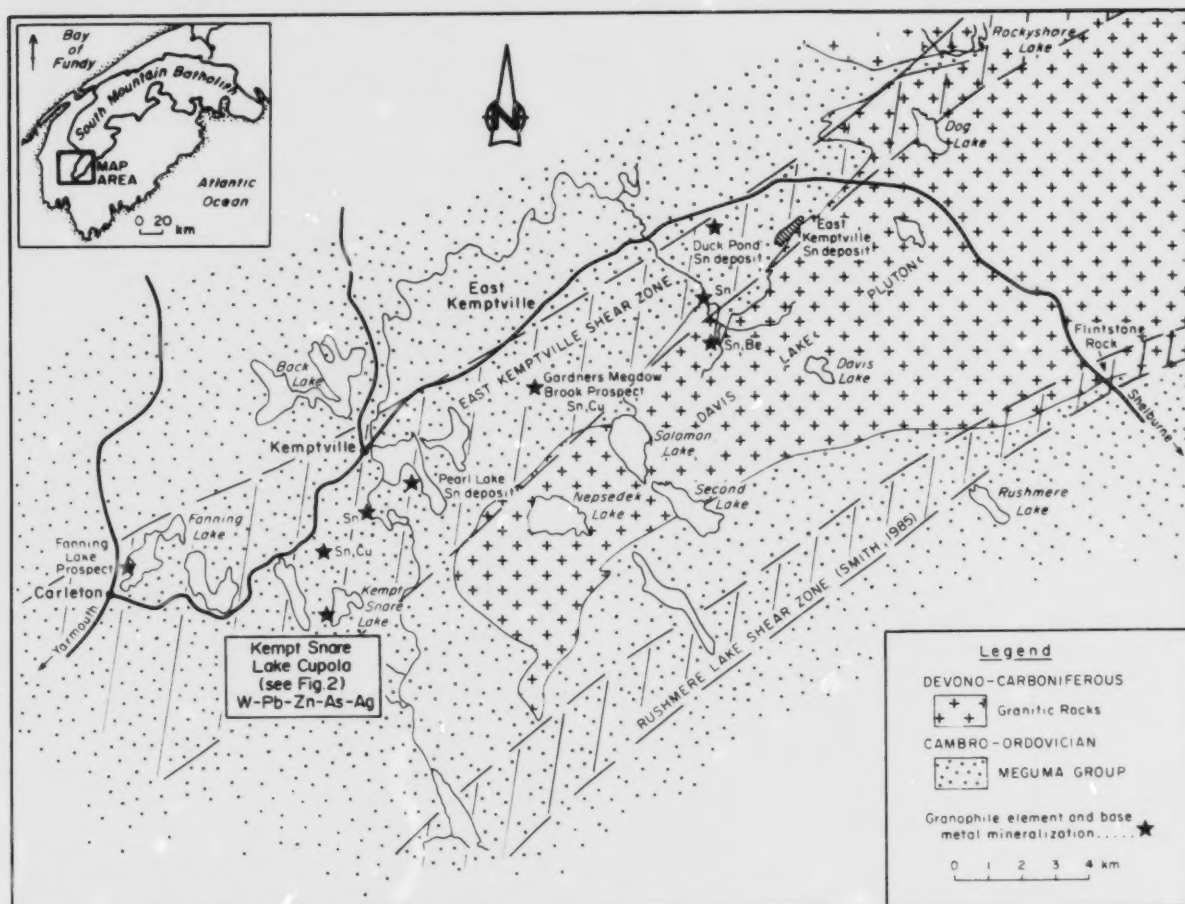


Figure 1. Geology map of southwestern Nova Scotia showing the location of the Kempt Snare Lake cupola relative to the Davis Lake Pluton and the East Kemptville Shear Zone with associated linear belt of deposits of granophile elements and base metals.

Zn-Ag values but did not find anomalous Au. By mid-century, exploration ceased and the site lay abandoned until reinvestigated by Taylor (1969) during a regional mapping survey. He reported that the quartz vein occurs in either a dark grey quartz-feldspar porphyry or a diorite porphyry.

Discovery of the East Kemptville tin deposit in the late 1970s resulted in intensive exploration activity in southwest Nova Scotia. This led to a re-evaluation of many deposits including the KSLC. Falconbridge Limited conducted till geochemical surveys in the area of the cupola in 1985 and 1986 and found anomalous values of Sn, W, Zn and Ag (Duncan, 1986a). Duncan (1986b) recognized that the veins are hosted by a greisenized granite, and that scheelite occurs both within the veins and the greisen. The till anomalies discovered by Falconbridge Limited were followed up with 3 diamond-drill holes of 70.1, 80.3 and 50.0 m respectively (Fig. 2; Jensen, 1987). Assays from core samples did not detect Au mineralization or economic concentrations of base

metals or W. However, the widespread occurrence of quartz veining and the presence of several zones of high Ag indicates that the mineral potential of the cupola and the exo-contact metasediments has not been fully assessed.

GEOLOGICAL AND PETROGRAPHIC RELATIONS

A plane table map of the KSLC (Fig. 2) shows the locations of diamond-drill holes, waste rock dumps, trenches and shafts (now collapsed or water-filled). Only one outcrop remains, a brecciated, vuggy, arsenopyrite-bearing, quartz-muscovite-chlorite vein in black greisen at the mouth of a small shaft immediately west of the collar of DDH KS-86-1. The waste rock dumps consist mostly of light grey to black, fine- to coarse-grained greisenized granite. Throughout the dumps, quartz debris containing galena, sphalerite, arsenopyrite, pyrite, scheelite, siderite, calcite and fluorite is common. Only one sample containing tourmaline was found.

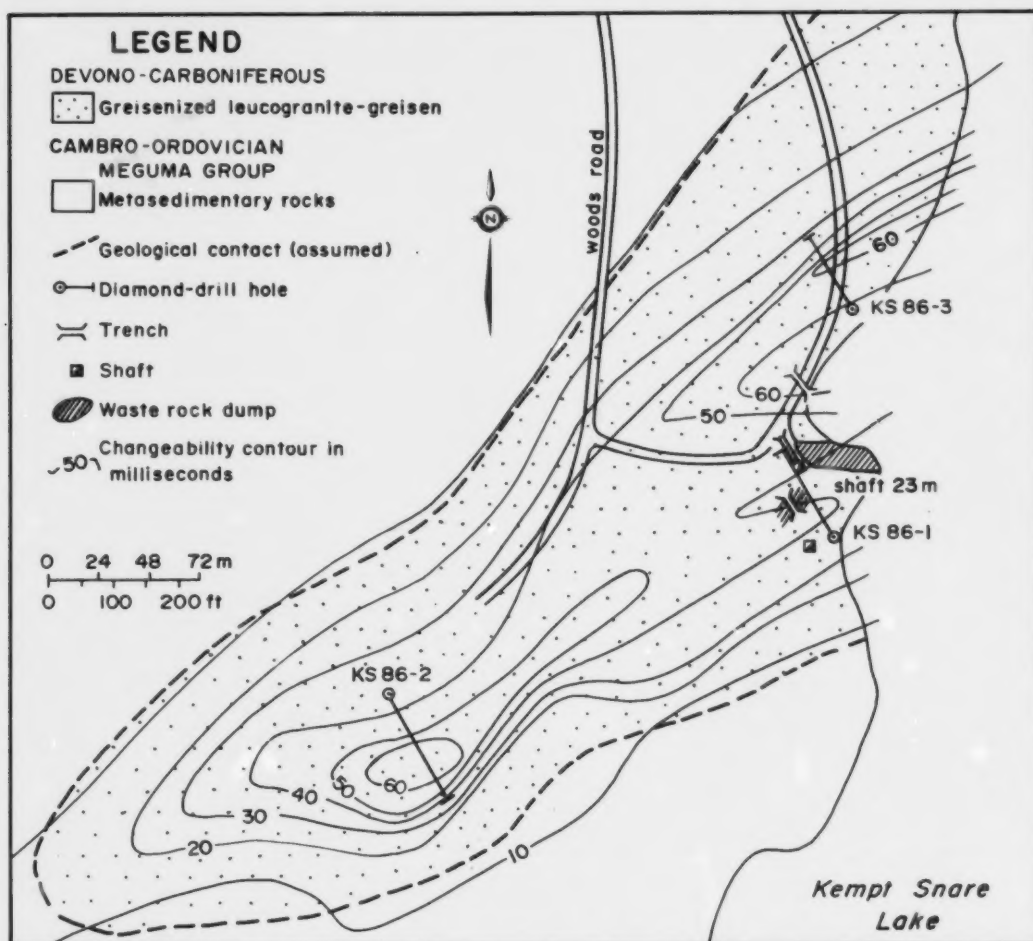


Figure 2. Plane table map of the Kempt Snare Lake W-Zn-Pb-As-Cu-Ag prospect showing the location of diamond-drill holes. Chargeability contours are from an IP geophysical survey of Kidd Creek Mines Limited (Duncan, 1986b).

The drill core was logged in detail and simplified sections from the logs are given in Figure 3. All 3 drillhole sections consist entirely of variably altered granitic rock intruded by numerous quartz veins. Five units are recognizable in the drill core based on texture, grain size and degree of alteration. The main features of the units are summarized in Table 1.

BLACK MEGACRYSTIC GREISEN

A medium grained, black, megacrystic greisen (BMG) comprises approximately 50% of the core and most of the dumps. The megacrystic texture results from the presence of 5-10% anhedral, subequant quartz megacrysts (4-10 mm). The black colour distinguishes this unit from most of the others and is the result of fine grained graphite pervasively distributed throughout the rock (see following section). The dark colour is mostly restricted to the feldspars and groundmass thus making the quartz "eyes" stand out.

GREY GREISENIZED GRANITE

A medium grained, grey, greisenized granite (GG) comprises 25% of the drill core and is present in all 3 drillholes (Fig. 3). The GG has a similar texture and grain size as the BMG but is distinguished by its lighter colour (less graphite). To some degree, the lighter colour makes the GG appear less megacrystic than the BMG but the 2 rock types have similar texture and grade into each other over a few metres. The GG is distinguished from the leucogranite (see following description) by having better developed textures indicative of hydrothermal alteration, such as muscovitized feldspars (Table 1).

FINE GRAINED GREISEN

A fine grained, grey (albitized) and black (greisenized) granite (FGG) comprises <5% of the drill core and is most commonly associated with

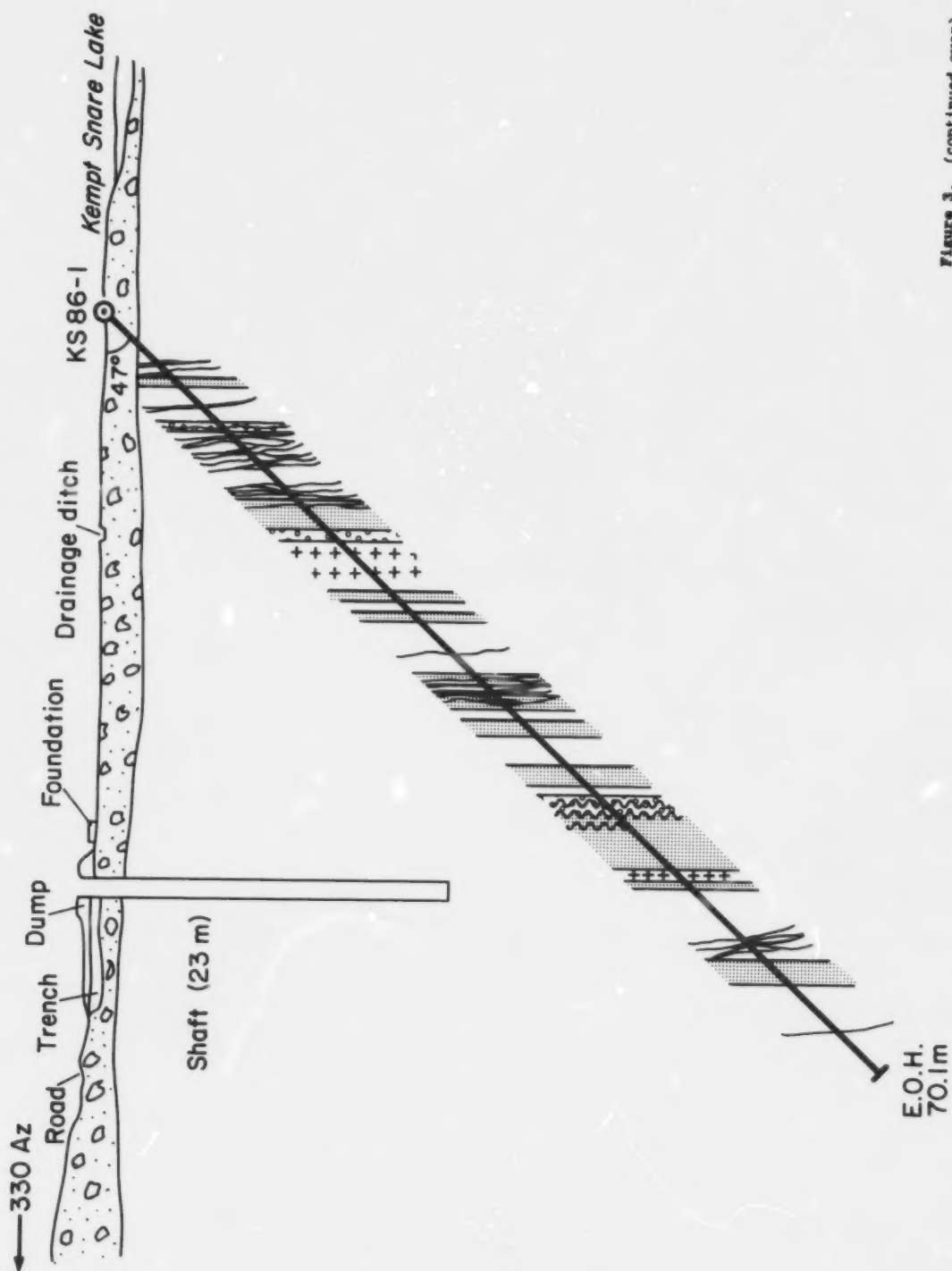


Figure 3. (continued over)

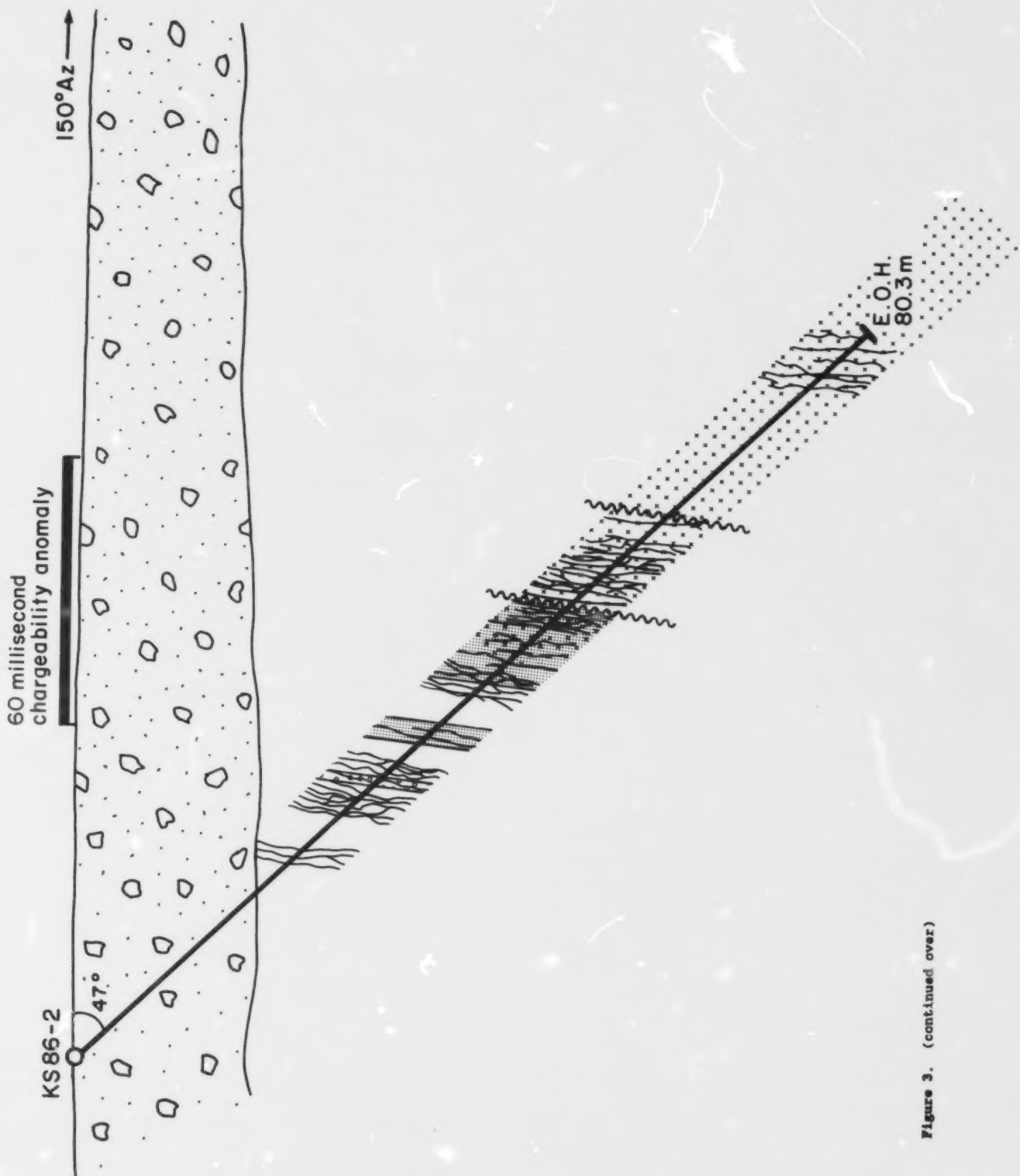


Figure 3. (continued over)

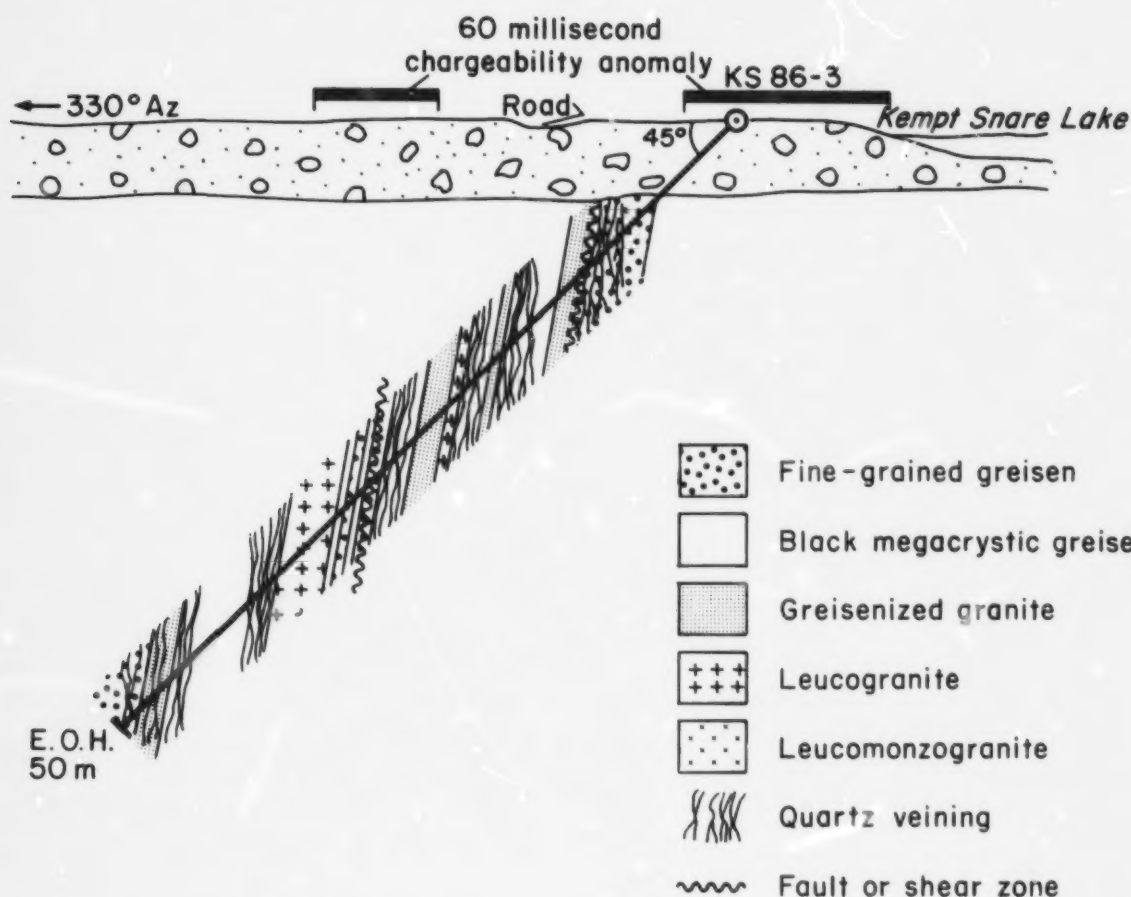


Figure 3. Generalized geological sections from diamond-drill logs of Soehl (1988) for drill core from the Kempt Snare Lake prospect (scale 1" = 10m).

intensely altered sections hosting numerous zones of quartz veins. These rocks are distinguished from the others by their fine grain size, absence of quartz megacrysts and, where present, their pronounced black colour. In the drill core the FGG is most abundant in DDH KS-86-3 (Fig. 3) but it is also found in the waste rock dump surrounding the shaft. The FGG grades into the BMG over approximately one metre.

LEUCOGRANITE

A light coloured, medium grained leucogranite (LGT; <2% mafics) comprises <5% of the drill core. The LGT only occurs in DDH KS-86-1 and 86-3 where it grades into both the GG and BMG (Fig. 3). The hypidiomorphic granular texture, light colour, and presence of discrete K-feldspar grains and only partially replaced biotite (chlorite

and/or muscovite) suggests that the LGT is a less altered variety of the GG and BMG.

LEUCOMONZOGRANITE

A coarse grained leucomonzogranite (LMG; ≈5% biotite) occurs in the bottom 30 m of DDH KS-86-2 where it is in fault contact with the LGT. The LMG has many coarse grained K-feldspar megacrysts (≈2cm), and biotite flakes that are variably altered to chlorite and/or muscovite. Texturally and mineralogically, the LMG resembles the coarse grained Davis Lake leucomonzogranite which is the dominant unit in the nearby Davis Lake Pluton (DLP) of the SMB (Ham and MacDonald, in press). The upper section of the LMG is intruded by quartz veins around which there is intense hydrothermal alteration. The alteration is manifest by muscovitized and

Table 1. Summary of geological and petrographic features of the Kempt Snare Lake cupola.

UNIT	MODAL FREQUENCIES ¹										CONTACT RELATIONS	Igneous	TEXTURES Alteration	Deformation
	Qtz	Ksp	Ab	Mt	Bl	Gr	Il	Acc	II	III				
Leucocratic granite	42	28	23	6	<5	a-1			zr, ap	cc	17	Arboreal-subhedral K-feldspar megacrysts (2mm). Interlocking grains. Biotite has minor inclusions and is altered to chlorite and muscovite. Subhedral albite laths.	Graphite is absent except in hydrothermally altered zones. Alteration increases toward sheared contact with leucocratic granite. Biotite is moderately to finely chloritized. Secondary muscovite after feldspar and biotite.	Deformation varies from moderate to intense near shear zone. Recrystallization of quartz along grain boundaries, fractures and twin planes. Bent and kinked twin lamellae and subgrain development are common.
Leucocratic granite	40	23	25	12	<2	a-r			zr, ap	cc	<5	Subhedral albite laths. Epigranular, interlocking grains. Perthitic K-feldspar. Coarse grained biotite and muscovite.	Partially to totally chloritized biotite. Coarser and finer-grained secondary muscovite common as alteration of feldspar and biotite.	Unblossed extinction and subgrain development of quartz. Kinked muscovite and albite common. Abundant faults.
Greisenized granite	39	32	20	9	0	a-r			zr, ap	cc	25	Interlocking grains of subhedral albite and anhedral quartz and K-feldspar. Coarse grained biotite and muscovite.	Biotite has been completely altered to muscovite and chlorite. Secondary albitic plagioclase is altered to coarse- and fine-grained muscovite.	Unblossed extinction and subgrain development in quartz. Bent twin lamellae in albite. Cataclastic texture in some zones.
Black Megacrystic Greisen	50	19	3	27	0	1			zr, ap	cc, asp	50	Megacrystic texture defined by quartz megacrysts (5-10). Subhedral to anhedral albite and perthitic K-feldspar.	Intense development of secondary fine- and coarse-grained muscovite from albite and K-feldspar. Many albite laths are completely muscovitized. Abundant graphite occurs as fracture fillings and as pervasive disseminations in feldspar and secondary muscovite. Pervasive graphite in K-feldspar suggests both minerals are secondary.	Fractured minerals and microshears are common. Subgrain development also common. Recrystallization along grain boundaries is well-developed. Kinking in coarse grained muscovite.
Fine-Grained (A) Black Greisen (B) Albite	3	21	1	75	0	1			asp, cc	sch, ap	<5	Muscovite pseudomorphs after albite retain subhedral form.	Intense development of secondary muscovite and graphite. Non-megacrystic texture is the result of fracturing and alteration of pre-existing minerals. Desilicification in some zones results in almost complete absence of free quartz.	Cataclastic texture and shear zones are common. Shears are defined by alignment of muscovite and lensoid quartz.

I Qtz = quartz
Ksp = K-feldspar
Ab = albite
Mt = muscovite

Bl = biotite
Gr = graphite
Acc = accessories

II Graphite content: a = absent
r = rare
1 = intense

III Accessory minerals: zr = zircon
ap = apatite
cc = carbonate
sch = schistite

fl = fluorite
asp = arsenopyrite
sch = schistite

sericitized feldspars and by biotite which is almost totally altered to chlorite and muscovite.

PARAGENETIC SEQUENCE

A gradation exists among all the units, except the LMG which is in fault contact with the LGT. The gradation and heterogeneity among the units often made subdivision difficult. The variation in texture and colour correlates with increasing intensity of hydrothermal alteration predominantly shown by increase of muscovite. The sequence from least to most altered is LGT-GG-BMG-FGG.

Unfortunately, the LMG only occurs in fault contact with the above sequence of altered rocks so whether it is intrusive or gradational with the LGT is unclear. The LMG has a distinctly different texture than the LGT and the fact that hydrothermal alteration overprints both rock types suggests that they are separate rock types that have been brought into juxtaposition by a fault.

OCCURRENCE AND IMPLICATIONS OF GRAPHITE IN THE CUPOLA

The pronounced black colour of the hydrothermally altered rocks in the KSLC is caused by the presence of fine grained graphite. Graphite was confirmed by whole-rock geochemical analysis for elemental C (see Geochemistry section) and is most abundant in the highly altered rocks. The graphite occurs as fillings in fractures and shear planes in the rocks, and along microfractures and as disseminations throughout the rock-forming minerals (Fig. 4a). The K-feldspar was the mineral most receptive to the graphite, followed by albite and muscovite. The presence of disseminated graphite in the K-feldspar suggests that the K-feldspar is secondary and formed during the episode of graphite precipitation. The relation of the graphite to the muscovite is also important as most muscovites are strongly affected with disseminated graphite whereas some are devoid of it (Fig. 4b). This indicates that the muscovitization occurred both before and after the period of graphitization, thus suggesting that the graphite is part of the hydrothermal alteration.

Throughout the world, metamorphic graphite occurrences are common, but graphite occurrences of hydrothermal origin are rare (Rumble et al., 1986). In this paper the occurrence of graphite is reported and some features from which general interpretations can be made are discussed briefly.

The presence of carbonate minerals in veins

and as disseminations within the KSLC indicates that the hydrothermal fluid was CO_2 -rich. Shearing and faulting not only played an important role in localization of the granite-derived fluids, but also could have served as a potential pathway for metamorphic fluids foreign to the system. There are 2 likely methods by which the graphite could have precipitated in the KSLC.

A metamorphic fluid in equilibrium with pelitic rocks rich in organic detritus can receive CO according to the reaction: $\text{C} + \text{H}_2\text{O} \rightarrow \text{CO} + \text{H}_2$ (Reaction 1; Weis, 1981). If an H_2O -saturated igneous intrusion is emplaced into these rocks then mixing of the magmatically derived and metamorphic waters is likely. Thus the resulting hydrothermal fluid could be CO -rich and, at temperatures of 600-750°C, the reaction $2\text{CO} \rightarrow \text{C} + \text{CO}_2$ (Reaction 2) is possible. The result would be to precipitate graphite and release CO_2 to the fluid.

Whether the KSLC intrudes organic-rich pelites is not known so the possibility of Reaction 1 cannot be confirmed. In any event, the occurrence of the KSLC along a major structural break like the EKSZ means that the cupola could have intercepted metamorphic waters which travelled great distances. Reaction 2 requires temperatures of 600-750°C which are consistent with the temperature of a late stage leucogranite intrusion. Once the melt is intruded, the post-magmatic reactions will likely occur at progressively lower temperatures. Therefore, if the graphite occurred in this manner then its appearance should coincide with an early, higher temperature stage of alteration. The relationship of the graphite to minerals such as the secondary muscovite and K-feldspar (Figs. 4a and b) suggests that the graphite precipitated during the formation of secondary K-feldspar and the initial stages of muscovitization. In addition, Reaction 2 releases CO_2 to the fluid. The release is consistent with the presence of carbonate minerals in the veins intruding the cupola which indicate the fluid was saturated in CO_2 .

A second process by which graphite can be precipitated involves a slight modification of the fluid-mixing model of Rumble and Hoering (1986). A magmatically derived fluid exsolved from the KSLC with $\text{CO}_2 > \text{CH}_4$ will eventually encounter a metamorphic fluid upon migration outward from the cupola. If the metamorphic fluid is in equilibrium with a pelite, $\text{CH}_4 > \text{CO}_2$ is possible. Upon mixing of the 2 fluids precipitation of graphite can occur according to the reaction $\text{CO}_2 + \text{CH}_4 \rightarrow 2\text{C} + 2\text{H}_2\text{O}$ if the proper conditions of temperature and pressure are met (Rumble and Hoering, 1986). In the absence of further

geochemical and isotopic data it is not possible to make more definitive conclusions on the nature of the fluid(s) involved in the origin of the hydrothermal graphite in the KSLC.

DEFORMATION

Most of the rocks of the KSLC have undergone either ductile or brittle deformation. Features indicative of ductile deformation are best developed within shear zones several metres wide that occur in all drillholes. Moderate to strong foliation is defined by both primary(?) and secondary muscovites, and is associated with mylonite zones in the order of 1-2 cm wide (Fig. 4c). Recrystallization and subgrain development of quartz is also well developed.

Evidence of brittle deformation is abundant. For example, faults and slickensides occur on an average of every 3-5 m with some highly faulted zones reaching 15 m in width. The faults have variable core axis orientations but most are 45°. Since the holes were drilled at a declination of -45° and normal to the northeast strike of the geophysical anomaly and EKSZ (Fig. 2), it is assumed that the predominant dip of the faults is near vertical. In all cases the brittle faults post-date the ductile shear zones.

On a microscopic scale, kinked cleavage traces in muscovite, albite with bent polysynthetic twin lamellae, and boudinaged feldspars indicate brittle-ductile to brittle deformation (Fig. 4d). The bent polysynthetic twins in albite are important because they indicate that either the albitization process pre-dated the brittle deformation or the deformational episode was long lived and continued to affect the rocks after the post-magmatic alteration terminated.

MINERALIZATION

Quartz veins hosting mineralization occur in all 3 drillholes (Fig. 3). The veins range from 1 mm to 1 m thick and, in several zones, occur every 5 to 20 cm. The veins consist mostly of massive, milky quartz but some have carbonate (calcite $\pm$ siderite $\pm$ dolomite) and fluorite. The veins and immediately adjacent wall rock are variably mineralized with, in order of decreasing abundance, arsenopyrite, sphalerite, galena, scheelite, chalcopyrite and minor amounts of pyrite and pyrrhotite.

The abundant crosscutting relationships of the veins and their relationships to the shear deformation features show their complex history. The presence of veins which pre-date and post-

date faulting indicates that either there were separate hydrothermal events or the introduction of the fluids was contemporaneous with the shearing and faulting.

ARSENOPYRITE

Arsenopyrite occurs most commonly along vein margins but also within the veins and as disseminations within the greisenized wall rocks. The crystals are euhedral and inclusion-free, with abundant fractured surfaces. Galena rims the arsenopyrite in many instances.

SPHALERITE

Dark brown-black, often submetallic, sphalerite occurs in veins as massive, rounded blebs as large as 5 cm in diameter. Yellow sphalerite (low Fe) occurs as rims on some grains and mantles of galena are common. The sphalerite crystals are highly fractured and typically contain inclusions of chalcopyrite and pyrrhotite.

GALENA

Galena occurs in the veins as irregular masses filling fractures and in the adjacent wall rocks as mantles (replacement?) on arsenopyrite and sphalerite. Galena is commonly intergrown with chalcopyrite, and also forms inclusions in siderite. Microprobe analyses of the galena show that Ag concentrations are as high as 0.21% (Soehl, 1988).

SCHEELITE

Scheelite occurs as cream-coloured grains disseminated in and around dark selvages of wall rock included within veins. In addition, significant amounts of scheelite occur as disseminations within the most extensively altered samples of BMG and FGG.

CHALCOPYRITE

Chalcopyrite occurs as inclusions in sphalerite or at sphalerite grain margins with pyrite. Some intergrowths with galena and inclusions within siderite also occur.

FLUORITE

Fluorite occurs as purple and/or green crystals in most veins but is particularly abundant in carbonate-rich veins. Minor amounts of small fluorite crystals occur disseminated throughout the groundmass of the most altered BMG samples.

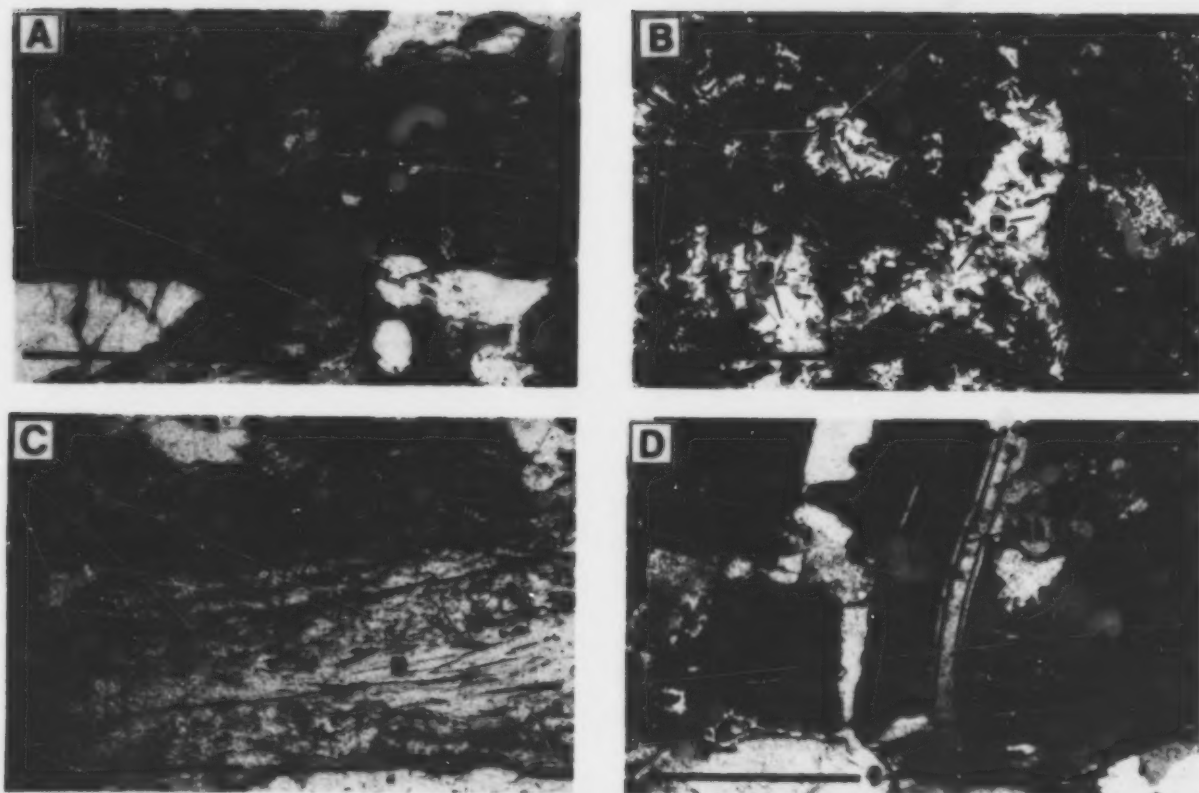


Figure 4. Photomicrographs from hydrothermally altered samples of the Kempt Snare Lake cupola: (A) pervasive (p) and fracture-controlled (f) graphite in K-feldspar (Kf); (B) secondary muscovite with (m_1) and without (m_2) graphite; (C) mylonite bands and aligned muscovites (m) in shear zone (note graphite (g) along shear planes); (D) albite (Ab) with bent polysynthetic twin lamellae. Scale bars on all photos = 1 mm.

CARBONATE

Siderite is the most common carbonate phase although calcite also occurs. The crystals are buff coloured and euhedral and are most abundant in small (<1 cm) veins where they are usually associated with fluorite. The siderite often contains inclusions of arsenopyrite, galena, sphalerite and chalcopryrite.

AGE RELATIONS

Mineral age dating by the $^{40}\text{Ar}/^{39}\text{Ar}$ stepwise outgassing method was done on 2 muscovites and a K-feldspar from the KSLC at Dalhousie University, Halifax. The age spectra of muscovites from a highly altered BMG and a relatively unaltered GG and of K-feldspar from a relatively unaltered LGT are given in Figure 5. The spectra for both muscovites have staircase patterns with the highly altered sample showing the lower age gradient. Initial argon released from both muscovites corresponds to an apparent age between 265 and 270 Ma whereas maximum ages are ≈ 303 Ma for the highly altered BMG and ≈ 332 Ma for the least altered GG. Apparent ages obtained for

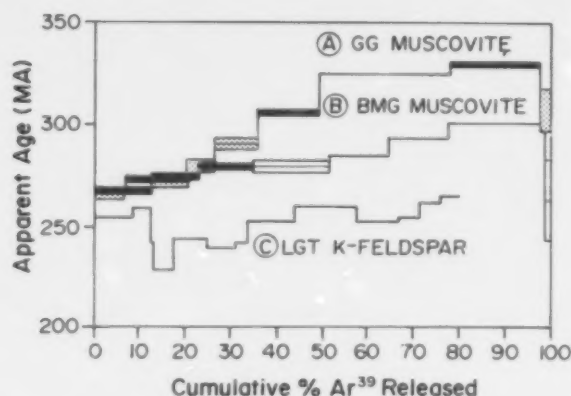


Figure 5. Age spectrum plots for 2 muscovites and one K-feldspar from the Kempt Snare Lake greisenized leucogranite cupola. (A) muscovite from a least altered greisenized leucogranite (GG); (B) muscovite from a highly altered black megacrystic greisen (BMG); (C) K-feldspar from a least altered leucogranite (LGT). Half heights of bars indicate 2σ relative uncertainties. Uncertainty in total age $\approx 1\%$.

the LGT K-feldspar are less than either of the muscovite values. The age spectrum appears to exhibit a weak age gradient from ≈ 230 Ma to ≈ 260

Ma over the majority of the gas release (note that because of a breakdown of the extraction furnace, this sample was not completely outgassed).

INTERPRETATION

Two models are proposed by Turner (1968) and Harrison and MacDougall (1982) to explain age gradients in $^{40}\text{Ar}/^{39}\text{Ar}$ spectra: episodic loss and slow-cooling. Ideally, minerals from an undisturbed rock yield perfect plateau ages (i.e. flat spectra) indicating the times at which each mineral passed below its blocking temperature. However, an overprinting thermal or deformational event affecting a mineral may result in (episodic) argon loss, the latter perhaps progressively less so from the rim to the core of a crystal. In the latter case, the sample has been incompletely outgassed by the overprinting event and a spectrum with increasing ages for successive temperature steps may result. The minimum initial ages therefore approximate the time of overprinting while the maximum age is indicative of the original cooling age of the mineral.

Slow-cooling of a mineral may also cause age gradients in spectra. However, in the KSLC, the presence of widespread post-magmatic hydrothermal alteration and deformation indicates that there was considerable post-intrusion thermal activity. In addition, the small size of the cupola argues against the required long time interval necessary for slow cooling. For these reasons the slow-cooling model is not considered applicable in this study.

The age spectra for both samples indicate that the minimum age of the overprinting event is 265 Ma. The maximum apparent age of the GG sample indicates that the KSLC is no younger than about 330 Ma. Although care was taken to select an undeformed and least altered sample of the GG, some degree of post-magmatic alteration and deformation has undoubtedly affected this rock. Consequently, the original magmatic age may be older.

The maximum age of ≈ 300 Ma for the highly altered BMG sample is consistent with one or both of two interpretations. The younger age may reflect a greater abundance of fine grained secondary muscovite relative to the less altered sample. This would mean that the hydrothermal event producing the secondary muscovite was either considerably younger than the age of the pluton (300 vs ≥ 330 Ma) or is the result of a hydrothermal event that spanned a long time interval. Evidence for a 295 Ma age for a greisenization event associated with mineralization

at the nearby East Kemptville Sn deposit is presented by Zentilli and Reynolds (1985). They interpret that the range from 270–300 Ma represents the duration of the hydrothermal event.

Another interpretation is that the intrusion and hydrothermal alteration are roughly of the same age and that the progressively younger spectra are predominantly the result of continued post-alteration shearing and faulting. This is supported by the textural relations described earlier which indicate that deformation occurred both during and after the hydrothermal event. Conceivably, the younger ages are a reflection of continued deformation and shearing along the EKSZ. Zentilli and Reynolds (1985) report a 350 Ma age for a muscovite in a leucogranite from immediately outside the ore-grade zones of the East Kemptville deposit. As the muscovites in both the greisens and leucogranites are secondary (Zentilli and Reynolds, 1985), the discrepancy in their dates may be related to processes other than hydrothermal alteration. Kontak (1987) recognized that the rocks of the East Kemptville deposit are deformed to varying degrees and that the younger date may actually represent an overprinting related to deformation.

The K-feldspar spectrum obtained in this study is very similar to those presented by Reynolds et al. (1987) for feldspars from plutons to the south of the study area. They interpreted the initial ≈ 220 –230 Ma apparent ages to reflect heating associated with the event that marked the initial rifting phase of the present Atlantic Ocean. It appears that, in the EKSZ, this late event caused major (but not complete) outgassing of the K-feldspar, but was not of sufficient intensity to disturb the more argon retentive muscovites.

GEOCHEMISTRY

Major and trace elements were determined on 10 representative whole-rock samples from the KSLC. All major elements except FeO, H_2O^+ , CO_2 and C were analyzed by X-ray fluorescence (XRF) at St. Marys University, Halifax. Analyses for FeO (titration); H_2O^+ (gravimetric); CO_2 (LECO induction furnace); and C (LECO induction furnace after HCl leach to drive off CO_2) were done at the Minerals Engineering Center, Technical University of Nova Scotia, Halifax (TUNS).

Trace elements Ba, Rb, Sr, Zr, Pb, Zn, Nb, Ga, Cu were analyzed by XRF at St. Marys University. Analyses for U, Th, W, Y, La, Ta, Hf, Cs, Ce and Au were carried out at Bondar-Clegg and Co. Ltd. by induced neutron activation analyses (^{197}Au plus

33 package"). Analyses for Bi, Mo, Sn, B (emission spec.); F (specific ion electrode, standard addition method); Li, Ag (atomic absorption); and As (colorimetric) were done at TUNS.

RESULTS

The chemical analyses (Table 2) show that most lithologic units have similar compositions. Assuming an average of the 2 LGT samples approximates the composition of the original unaltered LGT and an average of the 4 BMG samples their altered equivalents, Figure 6 compares the relative elemental enrichment and depletions associated with the hydrothermal alteration. The elements showing strongest enrichment as a result of the alteration are C, B, W, Sn, As, Zn, H_2O^+ , Fe_2O_3 , Rb, Y, K_2O , FeO, CO_2 and Li. Conversely, the elements showing greatest relative depletion are Sr, CaO and Na_2O . Elements essentially unchanged are P_2O_5 , Ba, U and TiO_2 .

The higher levels of K_2O , Al_2O_3 , H_2O^+ and Rb and lower levels of SiO_2 , Na_2O , CaO and Sr in the more altered BMG and FG relative to the less altered GG, LGT and LMG is consistent with the greater abundance of secondary K-feldspar and muscovite associated with the alteration (i.e. high Al_2O_3 , K_2O and Rb; Fig. 7a and b). The decrease of SiO_2 (i.e. desilicification; Fig. 7a) and the positive covariance of K_2O and H_2O^+ (Fig. 7b) in the more altered rocks suggests that muscovitization was an important alteration process. The decreasing trends of Sr and CaO reflect the albitization of original magmatic plagioclase and/or the replacement of secondary albite during the later stages of muscovitization.

The decreasing Na_2O with alteration (Fig. 7c) is consistent with the destruction of albite to form secondary K-feldspar and/or muscovite observed in petrography. Conceivably, this could be in response to an increase of the activity of K in the fluid and/or decreasing temperature of the post-magmatic reactions (Helgeson, 1985). These conditions will result in muscovite and K-feldspar replacing albite as the stable alkali species in post-magmatic reactions. The high levels of K_2O (up to 6.63 wt.%; Fig. 7b) suggest that decrease of albite was likely not dominantly temperature related and that there was at least some increase of K in the fluid phase.

The presence of graphite in the rocks is reflected in the content of C which ranges from 0.03 to 0.71 wt.% (Table 2). A plot of C vs. K_2O and H_2O^+ (Fig. 7d and e) shows the increase of C corresponds with an increase of both K_2O and

H_2O^+ . Because K_2O and H_2O^+ are indicators of alteration in the KSLC, their positive covariance with C suggests that the graphite was introduced by the same process that produced muscovitization. Another interpretation is that the rocks that were more susceptible to the passage of the K-rich aqueous fluids (more deformed rocks) would also be more receptive to passage of a later, non-related fluid from which graphite may have precipitated. However, the presence of secondary muscovites, both with and without graphite (Fig. 4b), indicates that the muscovitization process continued after the precipitation of graphite and therefore the graphite is not related to a superimposed younger event.

The LMG is chemically distinct from the other rock types in such elements as TiO_2 , Ce, La and Zr (Fig. 7f). These elements commonly reside in accessory mineral phases such as rutile, monazite and zircon which are (1) more abundant in less differentiated granitoids of the Meguma Zone (Clarke and Muecke, 1985) and (2) more resistant to hydrothermal alteration. The higher levels of these elements in the LMG compared with the other rocks of the cupola support the field and petrographic evidence that the LMG is a separate rock type. It possibly represents a slightly less differentiated rock brought from a deeper level into its present position by faulting.

COMPARISON OF KSLC WITH MEGUMA ZONE LEUCOGRANITES

The abundances of several elements not discussed above, compared with abundances in other Meguma Zone leucogranites, provide further evidence as to the nature of the KSLC. Chatterjee and Muecke (1982) recognized 2 distinct geochemical trends within the SMB based on U and Th distribution. They found that U increases with differentiation and progressive fluid-rock interaction but Th follows 2 trends (Fig. 8a). Throughout most of the SMB, increase of U is accompanied by Th decrease but in several areas of the batholith, the DLP for example, Th and U increase concomitantly. Also plotted in Figure 8a are the U and Th levels for the leucogranite hosting the Sn-bearing greisens of the East Kemptville Sn deposit (Kontak, personal communication) and the leucogranite I and leucogranite II suites for the SMB of Kontak et al. (1988). The leucogranite I suite formed predominantly by crystal-melt equilibria but in the leucogranite II suite, an anion-charged aqueous fluid phase played an important evolutionary role.

The levels of U and Th in the KSLC and the predominantly monzogranitic DLP as reported by

Table 2. Whole-rock major and trace element geochemical results for samples from the various granitic rocks and alteration facies of the Kempt Snare Lake cupola.

SAMPLE	86-2-8	86-1-2	86-3-3	86-1-4	86-1-6	86-1-1	86-2-4	86-3-1	86-2-3	86-3-9
ROCK TYPE ^I	LNG	LGT	LGT	GG	BNG	BNG	BNG	BNG	FGG	FGG
SiO ₂	76.69	75.81	76.17	75.64	70.02	75.20	74.75	73.31	74.34	75.43
TiO ₂	0.10	0.07	0.06	0.04	0.09	0.06	0.05	0.07	0.07	0.04
Al ₂ O ₃	12.46	12.88	12.89	13.59	15.70	13.50	13.51	14.59	13.59	13.39
Fe ₂ O ₃	0.43	0.36	0.35	0.36	0.69	0.30	0.45	0.79	0.74	0.44
FeO	0.60	0.67	0.60	0.47	1.27	0.57	0.70	0.87	0.70	0.70
MnO	0.09	0.05	0.05	0.02	0.12	0.07	0.14	0.07	0.03	0.04
MgO	0.69	0.72	0.61	0.71	0.90	0.78	0.72	0.76	0.83	0.73
CaO	0.49	0.49	0.32	0.32	0.06	0.39	0.19	0.11	0.05	0.31
K ₂ O	4.55	4.50	4.24	4.50	6.63	5.40	5.50	6.06	5.86	4.54
Na ₂ O	2.95	3.50	3.57	3.62	1.42	2.91	2.84	2.03	2.33	3.39
H ₂ O ⁺	0.62	0.62	0.60	0.66	1.44	0.85	0.94	1.04	0.89	0.72
H ₂ O ⁻	0.08	0.10	0.11	0.07	0.10	0.10	0.07	0.18	0.10	0.10
P ₂ O ₅	0.08	0.08	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.09
CO ₂	0.71	0.28	0.40	0.14	0.34	0.32	0.37	0.81	0.08	0.39
C	0.03	0.03	0.02	0.03	0.71	0.09	0.22	0.53	0.44	0.07
TOTAL	100.49	100.07	99.97	100.18	99.38	100.53	100.46	101.12	100.03	100.28
Fe ₂ O ₃ TOT	1.10	1.11	1.02	0.88	2.10	0.93	1.23	1.76	1.52	1.22
TRACES (ppm)										
As	18	124	275	63	1020	158	210	200	331	58.6
Ba	60	74	78	54	99	87	58	69	73	23
Bi	0.04	7.30	0.04	0.04	0.04	0.04	0.04	0.04	0.07	0.05
Cu	4	1	1	1	1	1	6	1	1	1
F	4080	1963	1380	820	2020	950	1260	1200	1600	2350
Mo	2	2	2	2	3	2	2	2	1	6
Pb	41	16	22	3	6	18	20	27	43	26
Rb	522	540	465	518	901	603	626	778	695	625
Sr	5.7	5.7	4.9	5.8	16.0	8.2	8.6	12.0	8.5	5.2
Sr	43	61	31	48	14	29	21	15	16	20
Ge	19	22	21	23	31	22	22	27	23	26
Zn	60	30	142	28	436	50	94	95	124	45
U	26.4	28.5	25.9	31.8	30.0	23.9	28.8	27.3	30.2	33.7
W	11	6	6	22	25	13	10	19	13	22
B	14	12	11	12	55	32	37	55	28	12
Y	60	44	47	40	75	57	55	66	43	44
Li	133	125	135	129	228	92	147	226	199	154
Th	25	24	15	16	20	19	24	25	23	16
Te	3.2	3.3	5.0	5.2	4.2	6.7	3.0	4.6	3.8	5.5
Hf	5	3	3	3	4	3	4	5	3	3
La	17	7	9	4	2	10	8	6	3	5
Nb	12	11	13	12	16	14	10	13	13	14
Ca	10	13	8.3	11	13	10	9.4	12	11	12
Ce	42	24	28	16	10	27	23	19	14	19
Zr	76	63	55	55	79	66	66	65	67	49
Ag	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Au(ppb)	<2	<2	<2	<2	<4	<2	<2	<2	<2	<2

LNG = Leucomonzonite
LGT = Leucogranite

GG = Greisenized Granite
BNG = Black Megacrystic Greisen

FGG = Fine Grained Greisen

Richardson (1988) fall along the increasing U and Th trend defined by Chatterjee and Muecke (1982). This contrasts with the leucogranite I and II suites of the SMB and, to a lesser extent, the East Kemptville leucogranite which follow the decreasing Th trend of the SMB (Fig. 8a). The dissimilarity in Th content between the East Kemptville leucogranite and the immediately adjacent DLP either provides some measure of support to the conclusion of Kontak (1987) that the East Kemptville leucogranite was formed by a

magmatic event separate to that which formed the SMB or that the East Kemptville leucogranite evolved from the DLP and the contrasting Th systematics are the result of an as yet unestablished process. In any event, the correlation of the U and Th systematics of the KSLC to the nearby DLP suggests a genetic link between these intrusions. Further data are required to make more definitive conclusions.

The K₂O and Rb data for the KSLC are given

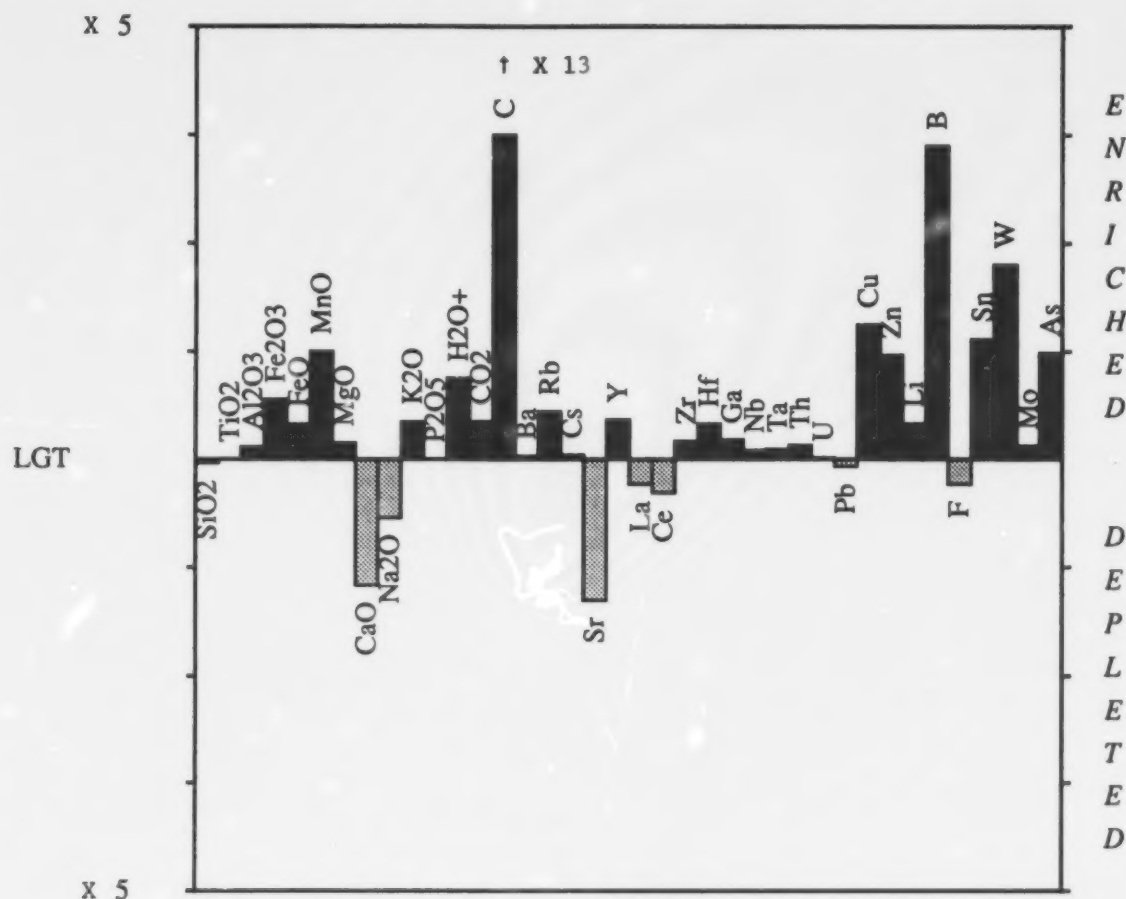


Figure 6. Diagram showing the elemental enrichments and depletions in the highly altered black megacrystic gneiss relative to the least altered leucogranite in the Kempt Snare Lake cupola. Assuming constant volume.

in Figure 8b. Also given are: (1) the field of magmatic rocks of the SMB (i.e. those formed by predominantly magmatic processes) from McKenzie and Clarke (1975), Chatterjee et al. (1983) and Richardson (1988); and (2) the leucogranite I suite (fluid-poor), leucogranite II suite and East Kemptville leucogranite (fluid-rich) of Kontak et al. (1988) and Kontak (personal communication).

The samples from the KSLC have K/Rb ratios ranging from 60–75 (Fig. 8b) but there is only a slight trend toward decreasing K/Rb with progressive alteration. A low K/Rb in granitic rocks is a feature consistent with formation from a system dominated by fluid-melt and/or fluid-rock interactions (Cerny et al., 1985). Although the KSLC samples do not show a pronounced trend toward lower K/Rb with progressive alteration their low ratio values, comparable to rocks formed in other late-stage fluid-dominated systems (Fig. 8b), attest to the fluid-rich environment in which the KSLC formed. The anomalously high levels of

K₂O distinguish the KSLC from the other leucogranite suites and may be testament to the K-rich nature of the alteration fluid.

CONCLUSIONS

The data presented in this paper allow the following conclusions on the geology, geochemistry and geochronology of the Kempt Snare Lake cupola.

1. The KSLC is a variably greisenized leucogranite-leucomonzogranite cupola believed to intrude Meguma Group metasedimentary rocks along the northeast-trending East Kemptville shear zone, approximately 4 km from the western extremity of the South Mountain Batholith.
2. The sequence of progressive post-magmatic alteration increases from leucogranite to greisenized granite, black megacrystic greisen and fine grained black greisen. The most

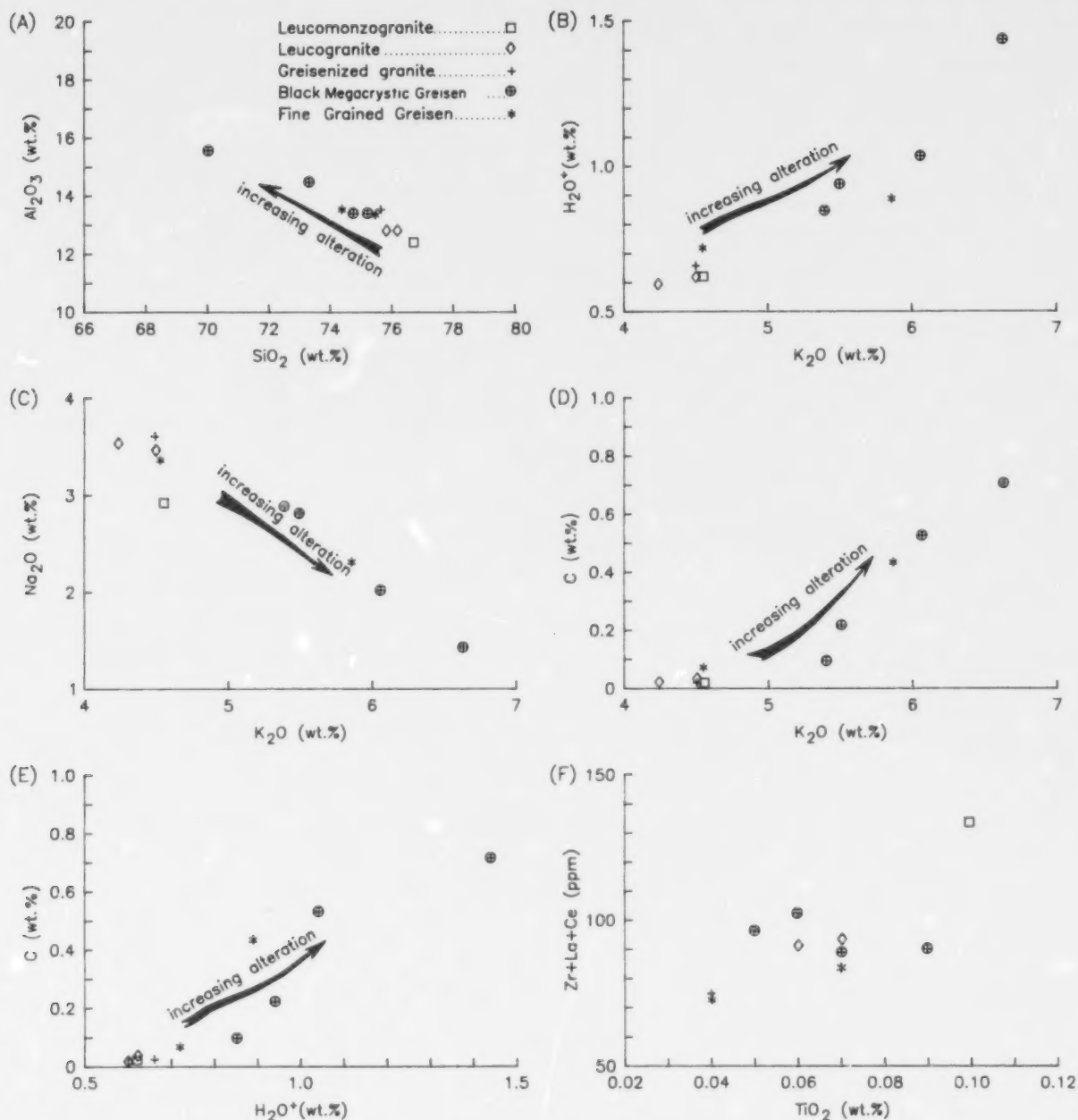


Figure 7. Plots of selected major and trace elements from the Kempt Snare Lake cupola.

altered rocks are associated with zones of quartz veins. A coarse grained leucomonzogranite is in fault contact with the leucogranite and likely represents a separate, less differentiated, granite brought into its present position from a deeper level by faulting.

3. The progression of hydrothermal alteration is marked by an increase of secondary muscovite. The abundance of secondary muscovite and K-feldspar indicates that K was the dominant alkali species in the alteration fluid.
4. The black colour in the rocks is the result of

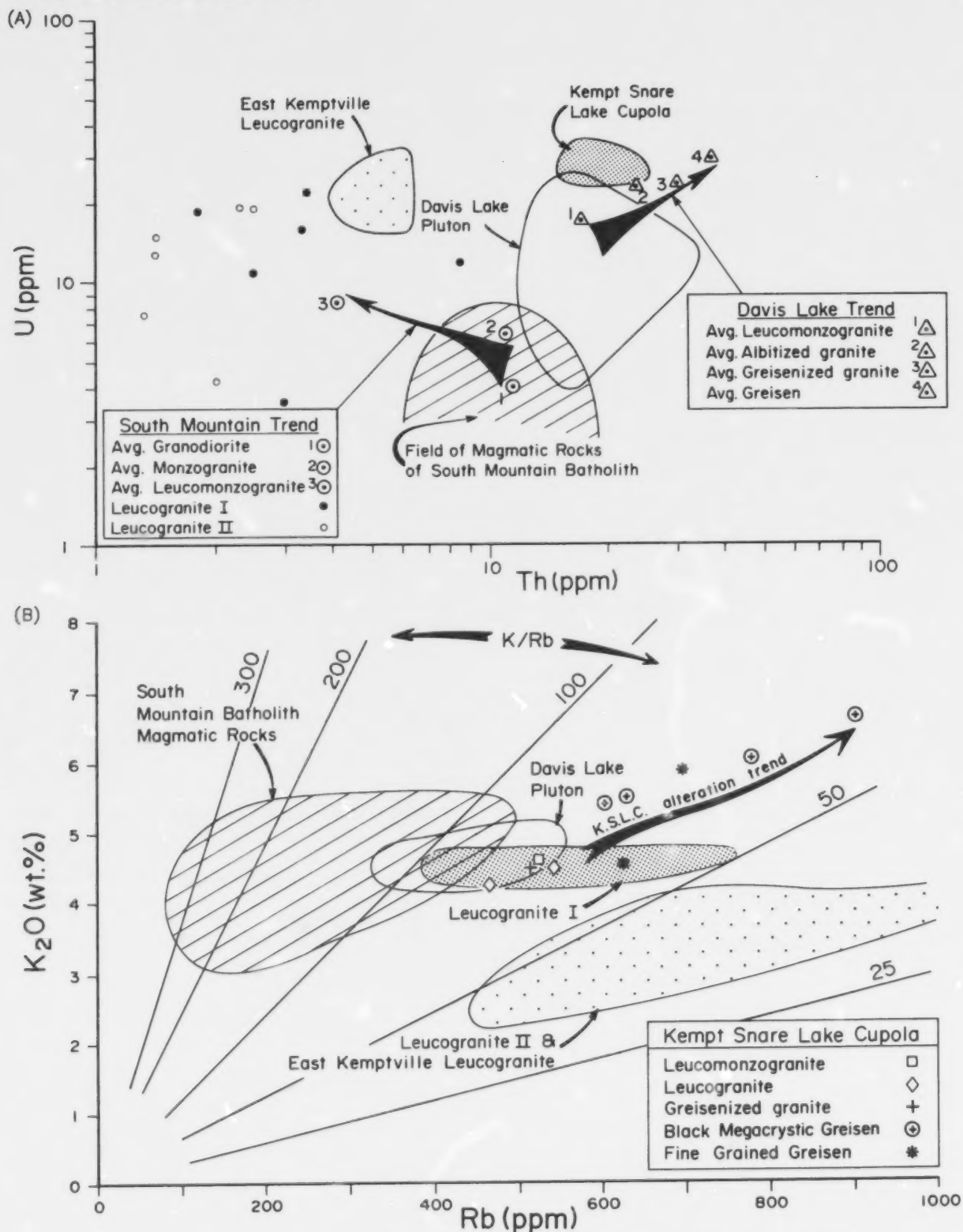


Figure 8. Plot of U vs. Th (plot A) and K₂O vs. Rb (plot B) for the Kempt Snare Lake cupola. Also given are: (1) the field of magmatic rocks of the SMB from McKenzie and Clarke (1975), Chatterjee et al. (1983) and Richardson (1988); (2) leucogranite I and II suites for the South Mountain Batholith of Kontak et al. (1988); and (3) East Kemptville leucogranite of Kontak (personal communication). Averages and trends of U and Th for the SMB and DLP are from Chatterjee and Muecke (1982).

fine grained pervasive and fracture-controlled graphite of hydrothermal origin. The precipitation of the graphite was contemporaneous with the muscovitization and is the most extensive occurrence of hydrothermal graphite in the granitic rocks of Nova Scotia.

5. The cupola is variably deformed and commonly displays features indicative of both ductile and brittle deformation. The deformation is best developed in the most intensely altered sections, suggesting a relation between the hydrothermal alteration and shearing.
6. Mineralization in the KSLC is mostly confined to quartz veins and their immediately adjacent wall rocks. In order of decreasing abundance the veins contain the economic mineral assemblage: arsenopyrite, sphalerite, argentiferous galena, scheelite and chalcopyrite. In addition, siderite and fluorite occur in the veins and wall rocks.
7. Age dating of 2 muscovites and a K-feldspar by the $^{40}\text{Ar}/^{39}\text{Ar}$ stepwise outgassing method indicate a minimum overprinting event affected the micas at 265 Ma and the K-feldspar at 220 Ma. A highly altered sample yielded a maximum plateau apparent age of 300 Ma while a less altered sample yielded a maximum plateau apparent age of ≈ 330 Ma. The widespread presence of deformation and alteration features in the rocks means the 330 Ma age can only be considered a minimum age for intrusion of the pluton. The 300 Ma age for the highly altered sample may be a reflection of continued deformation along the EKSZ.
8. The progression of alteration in the KSLC is marked by increase of K_2O , Al_2O_3 , H_2O^+ , Rb and C and decrease of SiO_2 , Na_2O , CaO and Sr. These increases and decreases are consistent with the hydration of pre-existing minerals by a K-dominated hydrothermal fluid. The increase of C reflects precipitation of graphite in the most altered units. The leucomonzogranite has higher levels of compatible elements such as TiO_2 , Zr, La and Ce. This supports the petrography and suggests that this is a less differentiated rock of separate origin from the others in the cupola.

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REGIONAL BIOGEOCHEMICAL SURVEYS FOR GOLD IN EASTERN NOVA SCOTIA, CANADA¹

P. J. Rogers and C. E. Dunn²

INTRODUCTION AND RATIONALE FOR REGIONAL BIOGEOCHEMICAL SURVEYS

Many exploration geologists feel that Canada is covered with an over-abundance of shrubs and trees which impede mineral exploration. This view overlooks the fact that biogeochemical surveys using plant tissue, phytogeochemistry, can provide valuable geochemical information about the substrate not obtainable by sampling other surficial materials. This is largely because trees and other plants, through their root systems, selectively extract elements from soils, groundwaters and bedrock. A large tree is capable of integrating, through its roots, the geochemical signature of many cubic metres of soil, bedrock, and groundwater that migrate through the substrate. Biogeochemistry can therefore provide a 'window' through surficial deposits to the underlying bedrock to provide important geochemical data that cannot be obtained from sampling other surficial media. Recent work at the Geological Survey of Canada (Dunn, 1988a) has tested and established rapid, practical and cost effective methods of vegetation sampling and analysis to assist the discovery of mineralization. Many biogeochemical studies have reported metal uptake processes, metal distribution patterns among species and seasonal fluctuations in chemistry. Although processes in the biosphere are extremely complex, field procedures can be simplified to make biogeochemistry a valuable and viable method for exploration (Dunn, 1988a, b).

In Canada reconnaissance level geochemical surveys using soils and lake sediments have succeeded in outlining broad regional patterns of metal abundance and have led to the discovery of significant mineral deposits (Shacklette and Boerngen, 1984; Hornbrook, 1988). However, few reconnaissance level biogeochemical studies have been conducted. This present study examines the merits of a regional approach utilizing phytogeochemistry which will provide new

insights to the substrate chemistry from reconnaissance level sampling (up to 1 sample per 50 km²) and its effectiveness for mineral exploration with particular reference to gold.

NOVA SCOTIA SURVEY AREA

In June 1987 a pilot project sampled vegetation at 2 km intervals along all passable roads and tracks in a 5000 km² area of the eastern Meguma Zone (MZ) of Nova Scotia, extending from just west of Beaver Dam eastward to Canso (Fig. 1). Eight hundred and fifty-four locations were visited during a 3 week period which included detailed sampling at approximately 200 sites over zones of known or suspected mineralization at the Beaver Dam gold deposit. The regional survey of about 650 sites has an average density of 1 site per 8 km². The total cost of the survey including collection, sample preparation and analysis was about \$30,000. The funding was supplied by the Geological Survey of Canada as part of the Canada - Nova Scotia Mineral Development Agreement 1984-1989.

REGIONAL GEOLOGY AND MINERALIZATION

The study area is underlain by Meguma Group (MG) metasediments of Cambro-Ordovician age. The lower turbidite sequence (Goldenville Formation) is conformably overlain by black slates (Halifax Formation). Deformation during the Acadian Orogeny produced tight to isoclinal, upright folds with accompanying regional greenschist to amphibolite facies metamorphism. Granitic bodies, sometimes of batholithic proportions, intruded the MG during the Acadian event (370 Ma). The South Mountain Batholith is the largest discrete intrusion in the MZ, although in the study area most of the intrusions are small in surface outcrop and are mainly located in the eastern half (Fig. 1). Most of the significant gold deposits of Nova Scotia are found within the MG, especially in the Goldenville Formation. These deposits contain native gold with arsenopyrite and

¹ Funded by Geological Survey of Canada under the Canada - Nova Scotia Mineral Development Agreement

² Geological Survey of Canada, 601 Booth Street, Ottawa, Canada K1A 0E8

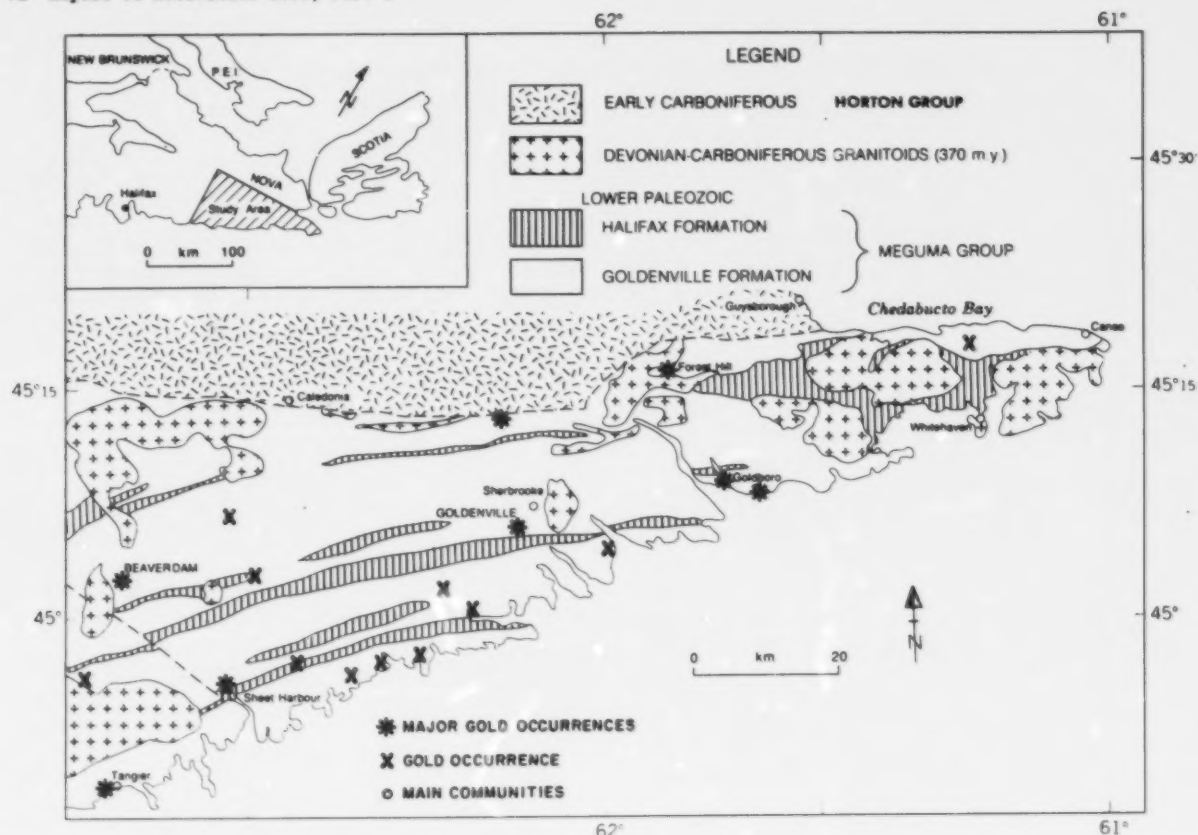


Figure 1. General geology of the eastern shore region of Nova Scotia.

carbonate in quartz veins. A series of northeast-trending anticlines and synclines form dome-like structures which are commonly associated with areas of gold enrichment. Kontak and Smith (1988) document the presence of wide zones of silicic, carbonate and phyllic alteration around these deposits which are also related to large scale shear zones.

SAMPLE MEDIA

The most common trees in the study area are balsam fir (*Abies balsamea*) and spruce (*Picea sp.*). The dominant spruce is red spruce (*Picea rubens*), with some white spruce (*Picea glauca*) and rare black spruce (*Picea mariana*) restricted mainly to the Canso area. In addition, alders (*Alnus crispa* and *Alnus rugosa*) are locally common, especially in areas of forest disturbance, but less abundant than fir and spruce. Deciduous trees (notably poplar, birch and maple) are locally common, but not as widely dispersed as the conifers and alders. In order to obtain an even sample medium coverage, the chosen species for each of the 650 sample locations are twigs of alder, balsam fir and spruce. Scales of spruce bark were collected at every fifth site, providing a sample density of 1

per 50 km². This report covers data obtained from the analysis of balsam fir twigs and spruce bark.

SAMPLE COLLECTION, PREPARATION AND ANALYSIS

Spruce bark scale samples are obtained by scraping 30-50 g of material into a paper bag with a blunt knife. Obvious contaminants, such as loose moss and sap globules are excluded. The outer scales are selected since the inner bark is chemically different from the outer dead tissues. Relatively strong enrichment of gold, arsenic and antimony is found in the outer bark (Dunn, 1988b).

The last 5 to 7 years' growth of balsam fir twigs from several branches were collected at least 50 m away from roads to minimize possible contamination. All samples were air dried, the fir needles removed, and ashed at 470° C. Ashing concentrates the trace metals of interest prior to INAA analysis of 0.5-1.0 g samples. No correction for variation in ash yield has been made to the data reported.

At Beaver Dam the same sample location grid and spacing were used as the previous soil and till

assessment surveys at the Mill Shaft area (Duncan, 1988; Coker et al., 1988).

REGIONAL BARK SURVEY: BIOGEOCHEMICAL PATTERNS

No attempt was made to obtain bark samples on an even grid distribution of the entire area mainly because bark could not be obtained easily at all the desired sample sites. It was intended that the survey remain as objective as possible, so the area was treated as if it was unexplored territory with no known gold mineralization. Consequently, contour patterns have been hand drawn objectively, without consideration to the nature of the underlying bedrock. Full details of this survey are given by Dunn (1988b).

The gold map (Fig. 2a) indicates strong gold enrichment in the vicinities of the Goldenville deposit and a large zone west of Forest Hill extending to Cross Roads Country Harbour, with another of lesser magnitude immediately to the northwest. In the east, there is slight enrichment (twice background) near the northern coast, and another in the south near Whitehaven. In the west a sample northwest of Beaver Dam contains 35 ppb gold and in the north, 7 km east of Caledonia, there is a single point anomaly of 100 ppb gold.

Arsenic values (Fig. 2b) range from 1 to 300 ppm with a median value of 10 ppm. Highest levels are in the Goldenville and Forest Hill areas, where there are above background values at a number of localities. The broad patterns of arsenic distribution are similar to those of gold, as would be expected because of the strong association of gold with arsenopyrite and loellingite in the Goldenville Formation.

Antimony, another pathfinder element for gold in Nova Scotia, has a tendency to concentrate in spruce bark. Antimony levels range from 0.8 to 21 ppm, with a median of 3.6 ppm. Antimony enrichment is found at gold and arsenic occurrences (Fig. 2c). There is noteworthy enrichment around the Chedabucto granite in the east with the highest concentration occurring near Whitehaven. In the west the site of gold enrichment near Caledonia has more than 3 times the background concentration of antimony. In addition, enrichment occurs at a site half-way between Beaver Dam and Tangier, in the vicinity of the Mooseland deposit (see Kontak and Smith, 1988).

Selenium (Fig. 2d), the fourth element, is a pathfinder element for various types of mineralization, and is not normally associated with

gold deposits of the Meguma Zone. Values in bark ash range from <2 to 15 ppm. There is a striking similarity in the distribution patterns of selenium and the other 3 elements shown on Figure 2. This indicates that selenium is associated with mineralization, and the biogeochemical enrichment of this element is substantiating evidence for the presence of mineralization.

Other elements, not shown, which exhibit similar distribution patterns are Co, Cr, Cs and Br. The reasons for the Cs and Br enrichments are uncertain, but their association with gold in vegetation from zones of gold mineralization has been noted at several localities in Saskatchewan (Dunn, 1985). It is worth noting that Br levels in western Nova Scotia are related to distance from the coast, which may explain some of the variation. Similar enrichments in Na and K are noted near the coast in a balsam fir twig survey by Dunn et al. (1989).

BEAVER DAM MILL SHAFT STUDY AREA: PRELIMINARY RESULTS

In addition to the reconnaissance level sampling, some detailed work was done at Beaver Dam over zones of mineralization which are concealed by glacial deposits at the Mill Shaft sampling grid. The detailed study area is located near the Mill Shaft about 1 km to the west of the principal ore zone of the Beaver Dam deposit (Fig. 3). The area was sampled by Seabright Resources in 1986 and 1987 as a joint option with Coxheath Resources (Duncan, 1988). The local geology shown on Figure 4 is taken from the Seabright drilling and surface mapping (Duncan, 1988). The area consists of Goldenville Formation quartzite with intercalated argillite horizons and 2 narrow auriferous veins are located near the Mill Shaft. The principal structure, an overturned fold called the Beaver Dam Anticline, is traced east-west across the property (Fig. 4). The immediate area is also traversed by a series of northwesterly trending fault zones (Smith and Kontak, 1988). To the south is located the River Lake Pluton and to the north the Liscomb Complex (Giles, 1985), both of which intrude Meguma Group metasediments.

The main till unit is a quartzite till (Duncan, 1988) which completely covers the area to depths of up to 6.5 m (Duncan, 1988). A detailed soil sampling grid using a 50 by 50 m line spacing was placed over the area (Duncan, 1988) and Kraft bag sized samples were taken for gold analysis. Coker et al. (1988) report on a detailed orientation study which was undertaken in the Mill Shaft area to evaluate the best sampling medium and size fraction for gold prospecting. The biogeochemical

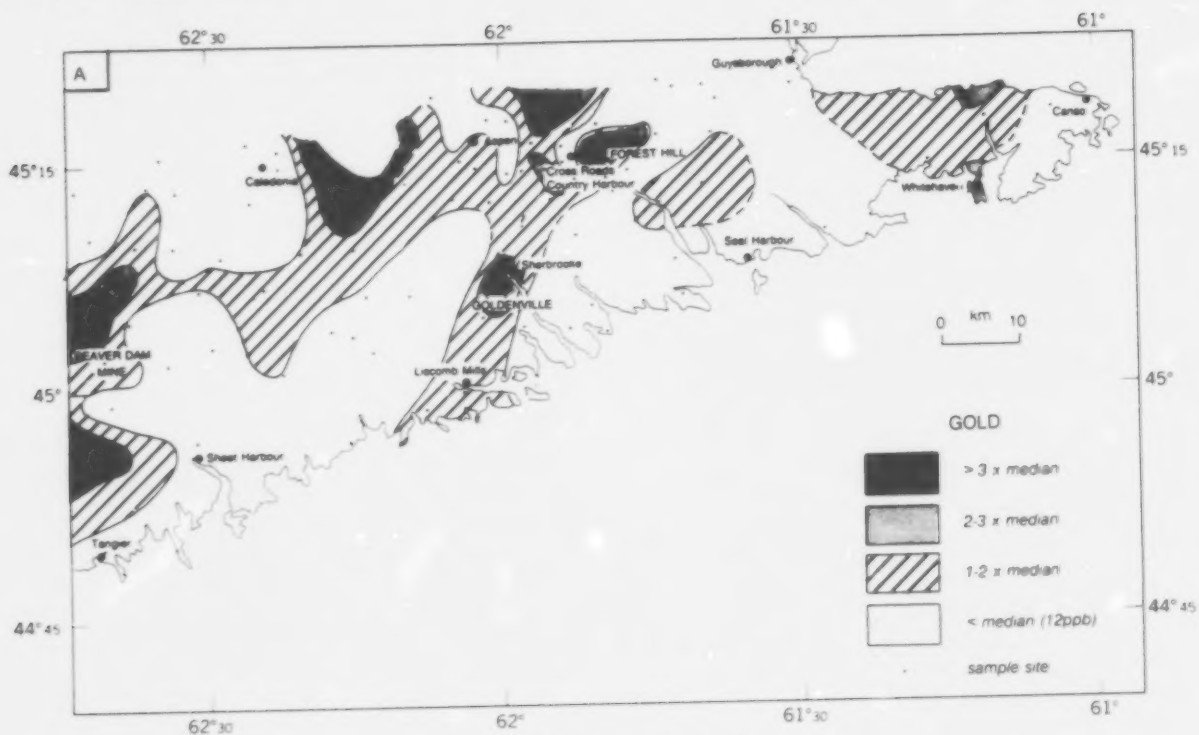


Figure 2a. Gold in ash of outer scales of spruce bark (from Dunn, 1988b).

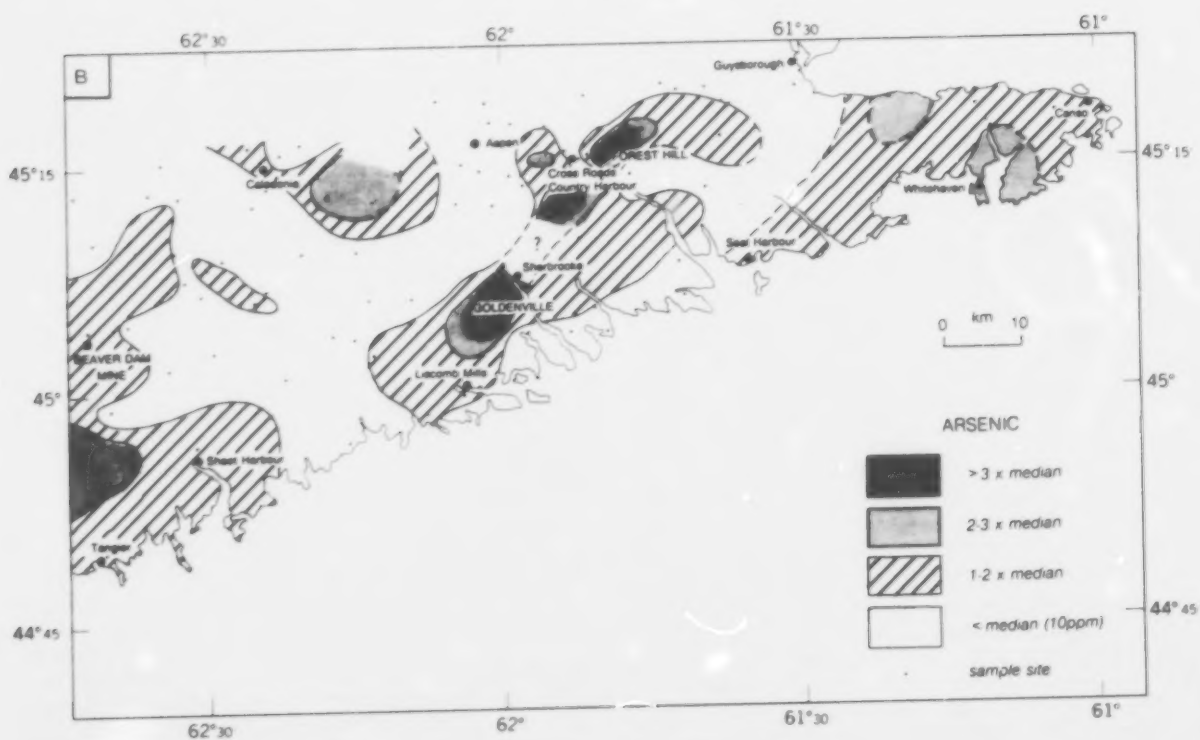


Figure 2b. Arsenic in ash of outer scales of spruce bark (from Dunn, 1988b).

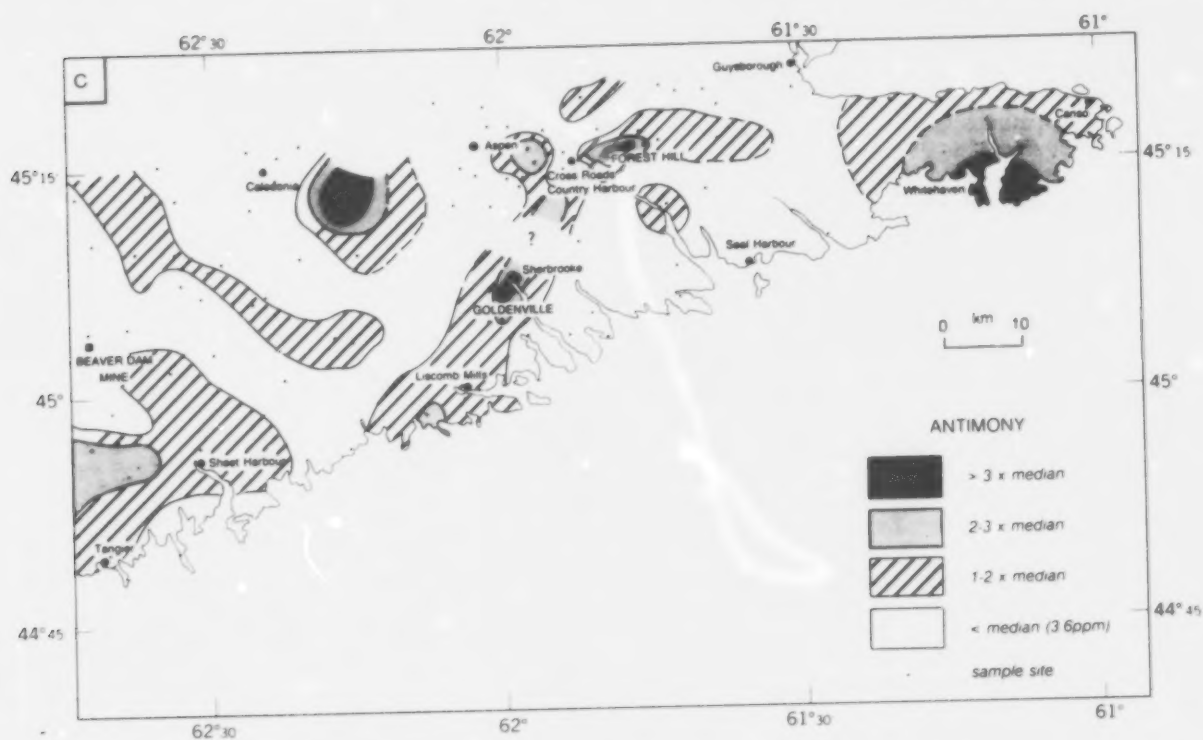


Figure 2c. Antimony in ash of outer scales of spruce bark (from Dunn, 1988b).

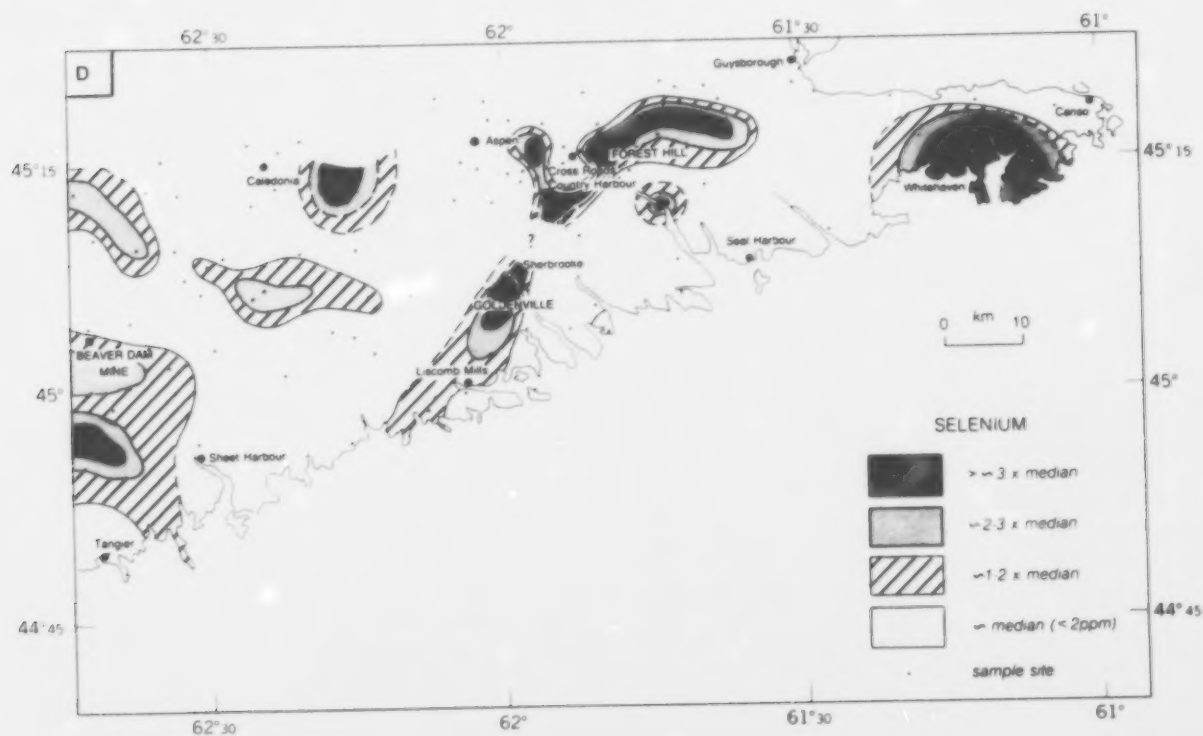


Figure 2d. Selenium in ash of outer scales of spruce bark (from Dunn, 1988b).

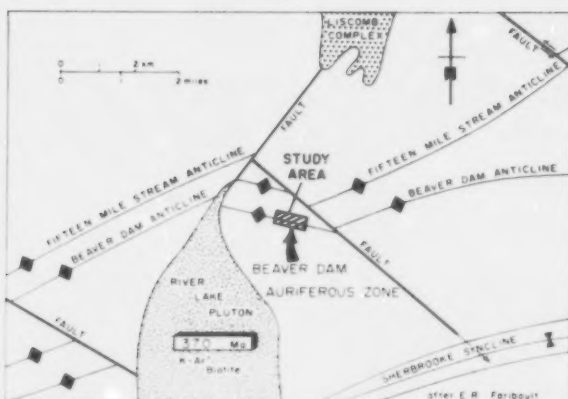


Figure 3. General geology of the Beaver Dam area (from Smith and Kontak, 1988).

survey was conducted in the same area to provide additional information on the geochemical signature of this type of deposit. The sampled area is poorly drained and has a mixed boreal forest cover with interspersed boggy areas. The biogeochemical survey was extended into these boggy areas, which could not be sampled by either till or soil methods, in an attempt to extend anomalous zones and to test this application of biogeochemical methods.

GOLD SURFICIAL GEOCHEMICAL RESPONSE IN THE MILL SHAFT AREA

The gold anomalies in the soil and till surveys indicate a narrow dispersal fan about 100 m wide extending some 300 m southeast from the gold-bearing quartz veins at Mill Shaft (Fig. 5). Both the till and soil surveys have southeasterly trending dispersal fans which parallel local striae and a head located about 50 m to the south of the veins' position. A similar pattern is also seen for antimony and arsenic in heavy mineral till samples (Coker et al., 1988).

The distribution of gold in red spruce bark scales also closely outlines a dispersal fan with values of up to 40 ppb gold (Fig. 6a). In this case, however, the biogeochemistry outlines a southeasterly dispersal fan whose head intersects the quartz veins at Mill Shaft. This pattern also closely outlines a vein quartz boulder train mapped on the surface (Lawyer, personal communication, 1989). An additional parallel fan, not detected by the grid soil sampling, is indicated about 100 m to the north of Mill Shaft. The area is boggy and could not be adequately sampled using till or soils. A similar and almost identical distribution is noted for arsenic in Figure 6b.

The balsam fir twig data for gold (Fig. 7a) present a complementary pattern to the spruce bark

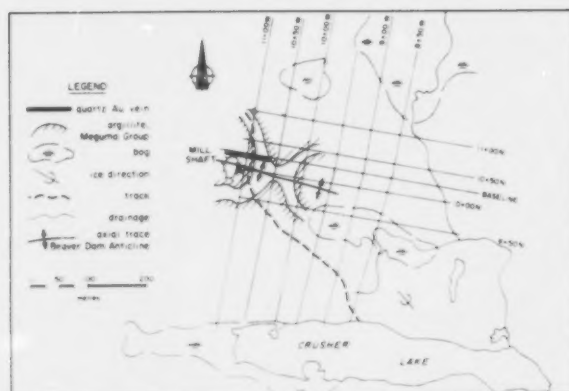


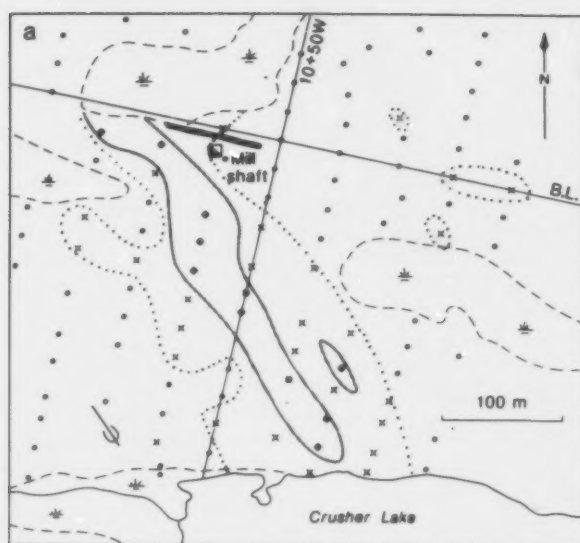
Figure 4. Mill Shaft study area showing location of detailed follow up grids (geology from Duncan, 1988).

data. The Mill Shaft mineralization is indicated by values up to 30 ppb gold. The strong southeasterly dispersal fan is more diffuse and not as pronounced as in the bark data (Fig. 6a). The other parallel northerly anomaly is also detected but again with a more subdued response. This indicates a differing response for gold in the spruce bark, especially in the west along lines 9 + 00 W and 8 + 50 W with values up to 70 ppb gold. The anomaly could be interpreted in a number of ways as the anomaly itself is not closed: the survey unfortunately did not extend past line 8 + 50 W. The anomalies lie in an east to west zone parallel to the Beaver Dam Anticline axial trace. This anomalous zone could also trend northeast, parallel to the regional fault trend. The area was not drilled off, the geology is complicated and the geophysical response is complex (D. Forgeron, personal communication, 1989). Arsenic values are quite similar to the gold values. This appears to be a promising area worthy of follow-up investigation.

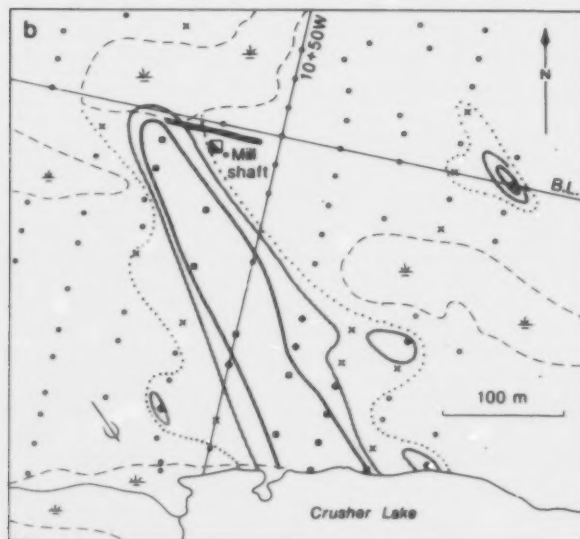
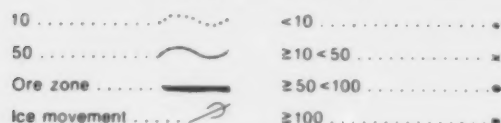
CONCLUSIONS

A regional biogeochemical survey using either red spruce bark or balsam fir twigs is capable of detecting regional geochemical patterns related to known gold deposits in eastern Nova Scotia. Known pathfinder elements for Au, such as As and Sb, have similar enrichments while Se, Co, Cr, Cs and Br in spruce bark scales are also worthy of note as indicators of mineralization, even at the reconnaissance scale of 1 sample per 50 km². More defined patterns are noted in balsam fir twigs at a sampling density of 1 per 8 km² with sympathetic Au and As enrichment near known mineralization.

The biogeochemical survey, at a cost of about \$30 per sample, represents a reliable, inexpensive and extremely effective exploration method for gold and other elements. Detailed sampling of



Au (ppb) B Horizon Soil



Au (ppb) HMC

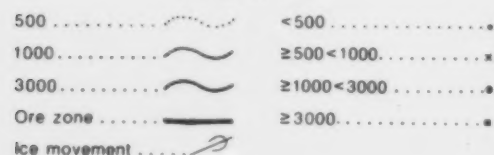


Figure 5. Gold values in (a) soil B horizon samples and (b) till heavy mineral concentrates in the Mill Shaft area (from Coker et al., 1988).

bark or twigs at a known gold occurrence produces similar gold distribution patterns to those in soils or tills. Additionally, the biogeochemistry is capable of extending anomalies into swampy areas. Unexpected patterns of gold enrichment in the biogeochemical samples of bark and twigs are also found in areas where there is only a sporadic response in either till or soil.

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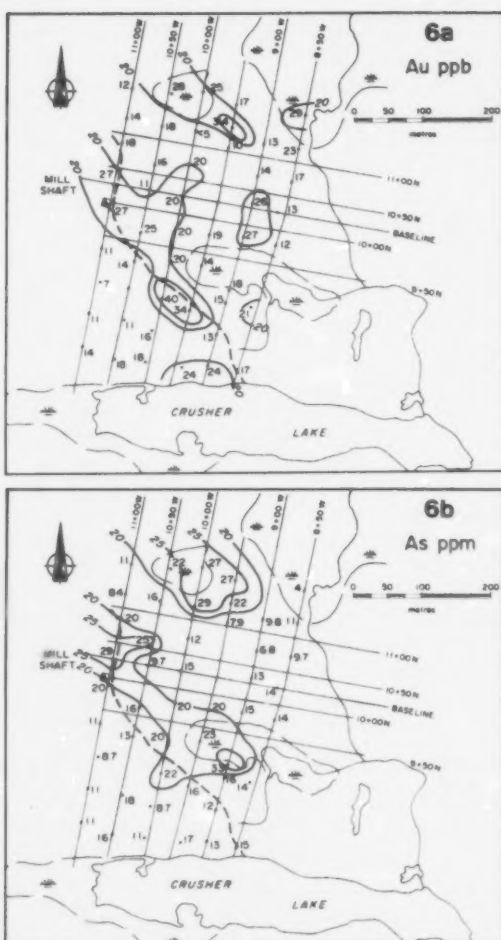


Figure 6. Red spruce bark data in the Mill Shaft area for (a) Au and (b) As.

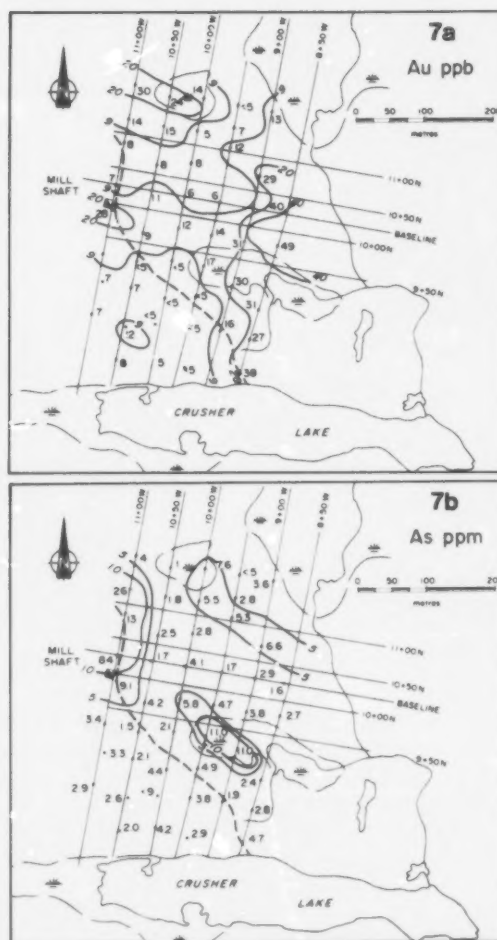


Figure 7. Balsam fir twig data in the Mill Shaft area for (a) Au and (b) As.

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GEOCHEMICAL ATLAS DATABASE: PROGRESS REPORT¹

P. A. Lombard

INTRODUCTION

A comprehensive database management system has been established to process data acquired from several regional geochemical surveys conducted by the Nova Scotia Department of Mines and Energy (NSDME) between 1977 and 1987. Thus far data have been compiled for the 1982-83 stream sediment survey. For each National Topographic System (NTS) 1:50 000 scale map sheet in the survey boundary a graphical representation (intensity symbol plot) was produced at 8½" x 11". In addition, for the 1982-83 stream sediment data cumulative frequency histograms were produced for each NTS map sheet. Once all of the data have been released as open files new basic geochemical interpretations can be achieved. The long term objectives of establishing a geochemical database will be geochemical interpretations achieved at larger scales, such as 1:250 000, and production of a regional geochemical atlas which will present map plots of element concentrations for the Province at a scale of 1:100 000.

The initial stage of producing a geochemical atlas involves the establishment of a geochemical database. Application of a database system to analytical results from many of the regional geochemical surveys conducted by NSDME (Table 1) enables quick retrieval and manipulation of the data. Recently purchased Datamine software enables geochemical data to be presented as intensity symbol plots and histogram/cumulative frequency diagrams for each element analyzed.

GEOCHEMICAL ATLAS

The work accomplished for the geochemical atlas so far includes: (1) establishment of a database for the analytical results from several geochemical surveys conducted by NSDME and (2) a systematic cataloguing of all geochemical assessment reports submitted to NSDME from 1965-1987 (Lombard and Rogers, 1988). Using the facilities available at the NSDME library, 610 assessment reports

Table 1. Raw data available in various software packages for regional geochemical surveys conducted by Nova Scotia Department of Mines And Energy.

Regional Surveys	----- Raw Data Output -----			
	Ascii	DBase III	Lotus 123	Datamine
1985 LAKE SEDIMENT	*	*	*	*
1983 LAKE SEDIMENT	*	*	*	*
1977 LAKE SEDIMENT	*	*	*	*
1982-83 STREAM SEDIMENT	*	*	*	*
1983 STREAM WATER	*	*	*	*

* Raw data available with sample numbers and NTS map sheet.

¹ Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement
NSDME Report 89-1

produced by private industry have been examined and summarized, in addition to the reports produced by NSDME geologists. A geochemical atlas that includes both private industry results and results from NSDME surveys will enable better geochemical interpretation of areas in Nova Scotia. Data from four regional geochemical surveys conducted by NSDME have been entered into the database (Table 1). Data from the 1986-87 stream sediment survey will also be entered once they have been released as an open file report. Boundaries of the four regional sediment surveys entered into the database are shown in Figure 1.

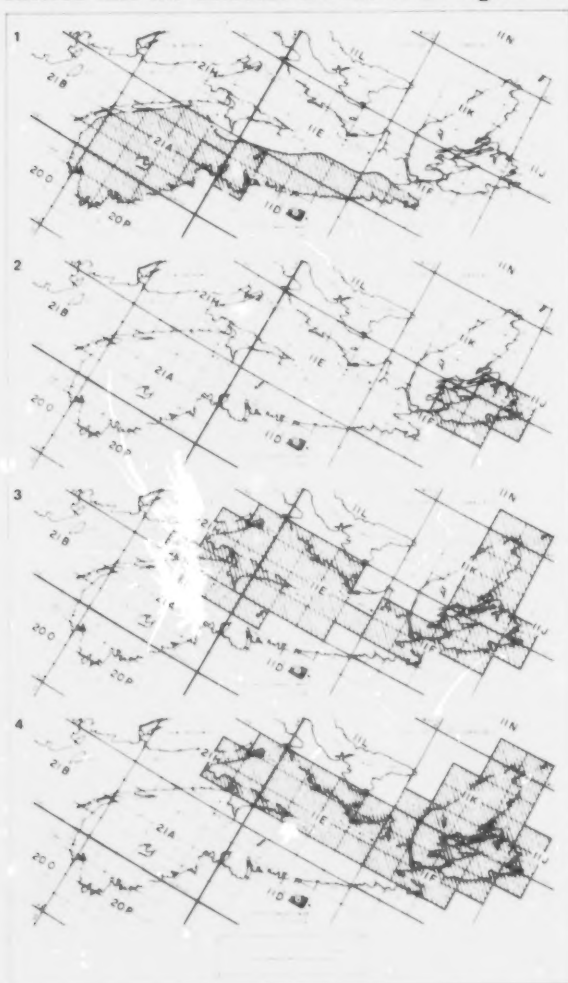


Figure 1. Boundaries of the four recent regional geochemical surveys conducted by NSDME and entered into the geochemical atlas database. (1) Lake bottom survey-reanalysis of 1977 lake sediments; n = 1813; Rogers and MacDonald, 1985, (2) Lake bottom survey; n = 394; Rogers and MacDonald, 1984, (3) Stream sediment survey; n = 5324; Rogers and MacDonald, 1984, (4) Precious metals-bulk stream sediment survey; n = 3073; Lombard and Mills, 1987.

The database was established using Datamine software which is programmed to the compatible base version of an IBM PC/AT with 640 kb memory, 80287 maths co-processor, 20Mb hard disk, and a high capacity 1.2 Mb diskette drive. Datamine software allows the user to produce various geochemical statistics and element intensity plots. The software has the capability to produce publication quality printouts. At the departmental office, Datamine software is available for use on a Compaq 386 computer.

Table 2. Elements and properties analyzed for regional geochemical surveys conducted from 1983-1985. F, U and pH analyses were also obtained for 1983 lake water survey, 1983 stream water survey and 1986-87 stream water survey.

	1985 LAKE SEDIMENTS	1983 LAKE SEDIMENTS	1977 LAKE SEDIMENTS	1982-83 STREAM SEDIMENTS	1986-87 STREAM SEDIMENTS
Au	*	*	*	*	*
Cu	*	*	*	*	*
Pb	*	*	*	*	*
Zn	*	*	*	*	*
Ag	*	*	*	*	*
F	*	*	*	*	*
Li	*	*	*	*	*
Nb	*	*	*	*	*
Rb	*	*	*	*	*
Sn	*	*	*	*	*
Zr	*	*	*	*	*
Ti	*	*	*	*	*
Sb	*	*	*	*	*
As	*	*	*	*	*
Th	*	*	*	*	*
W	*	*	*	*	*
Ni	*	*	*	*	*
Mo	*	*	*	*	*
Fe	*	*	*	*	*
Hg	*	*	*	*	*
V	*	*	*	*	*
Cd	*	*	*	*	*
Co	*	*	*	*	*
Mn	*	*	*	*	*
U	*	*	*	*	*
Ca	*	*	*	*	*
Mg	*	*	*	*	*
Cr	*	*	*	*	*
Se	*	*	*	*	*
Zr	*	*	*	*	*
Ta	*	*	*	*	*
Eu	*	*	*	*	*
Tb	*	*	*	*	*
Yb	*	*	*	*	*
Ce	*	*	*	*	*
Ba	*	*	*	*	*
La	*	*	*	*	*
Hf	*	*	*	*	*
Ir	*	*	*	*	*
Sc	*	*	*	*	*
Na	*	*	*	*	*
Bi	*	*	*	*	*
Ni	*	*	*	*	*
K	*	*	*	*	*
Al	*	*	*	*	*
LOI ¹	*	*	*	*	*

¹LOI - Loss On Ignition

* - Data Available

+ - Inconsistent results due to excessively high detection limits

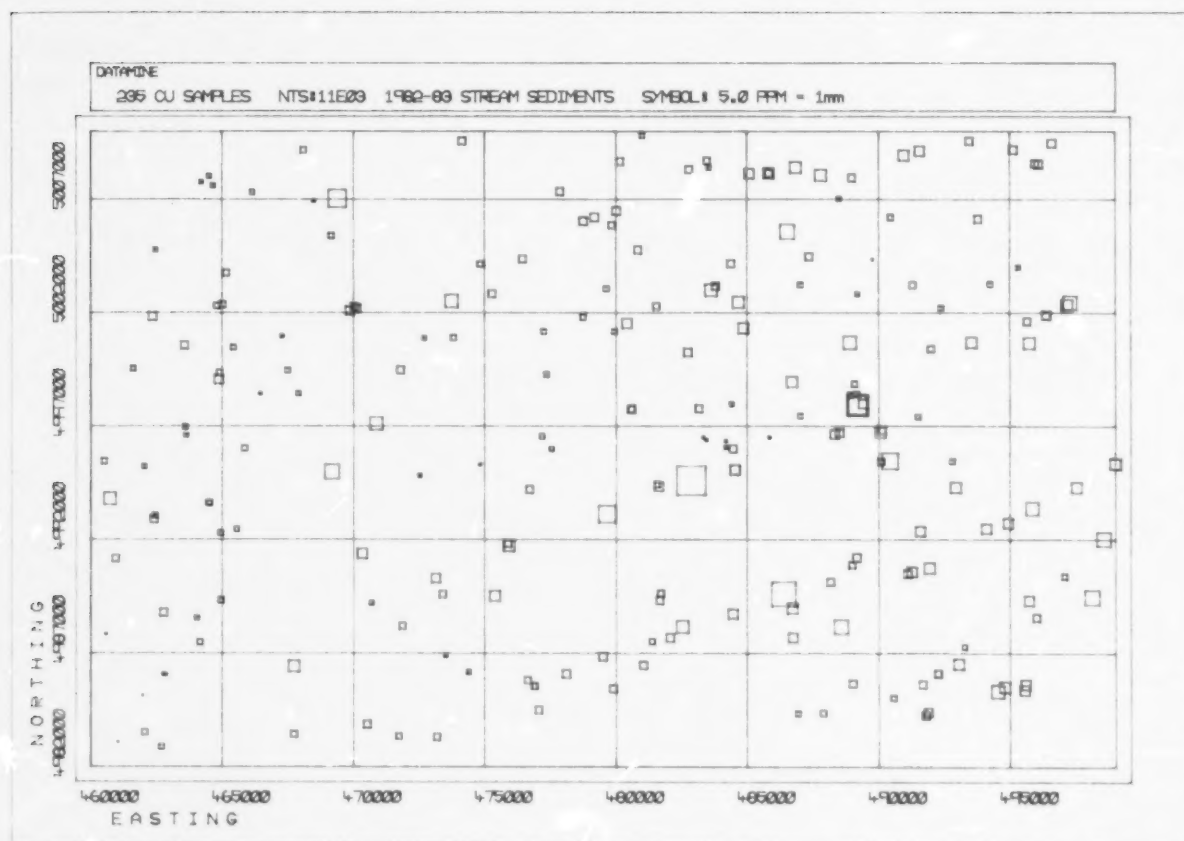


Figure 2. Example of a Datamine software 1:50 000 NTS map sheet variable element intensity plot. This particular plot shows Cu intensity for map sheet 11E/03. In the dataset for 11E (1:250 000 Open File release) the largest value is given the maximum 2 cm box size and the remainder are averaged accordingly.

OPEN FILE REPORT

The database established includes analyses for various elements from each regional survey (Table 2). The preliminary objective of the geochemical atlas project is to present the database as a series of open file reports summarizing all available geochemical data. For each 1:50 000 NTS map sheet in each of the surveys, the open file reports will include: (1) intensity symbol plots for various elements and (2) histograms and cumulative frequency diagrams derived for various elements. An example of the element intensity plot from the Datamine package is given in Figure 2 and the histogram cumulative frequency plot is illustrated in Figure 3.

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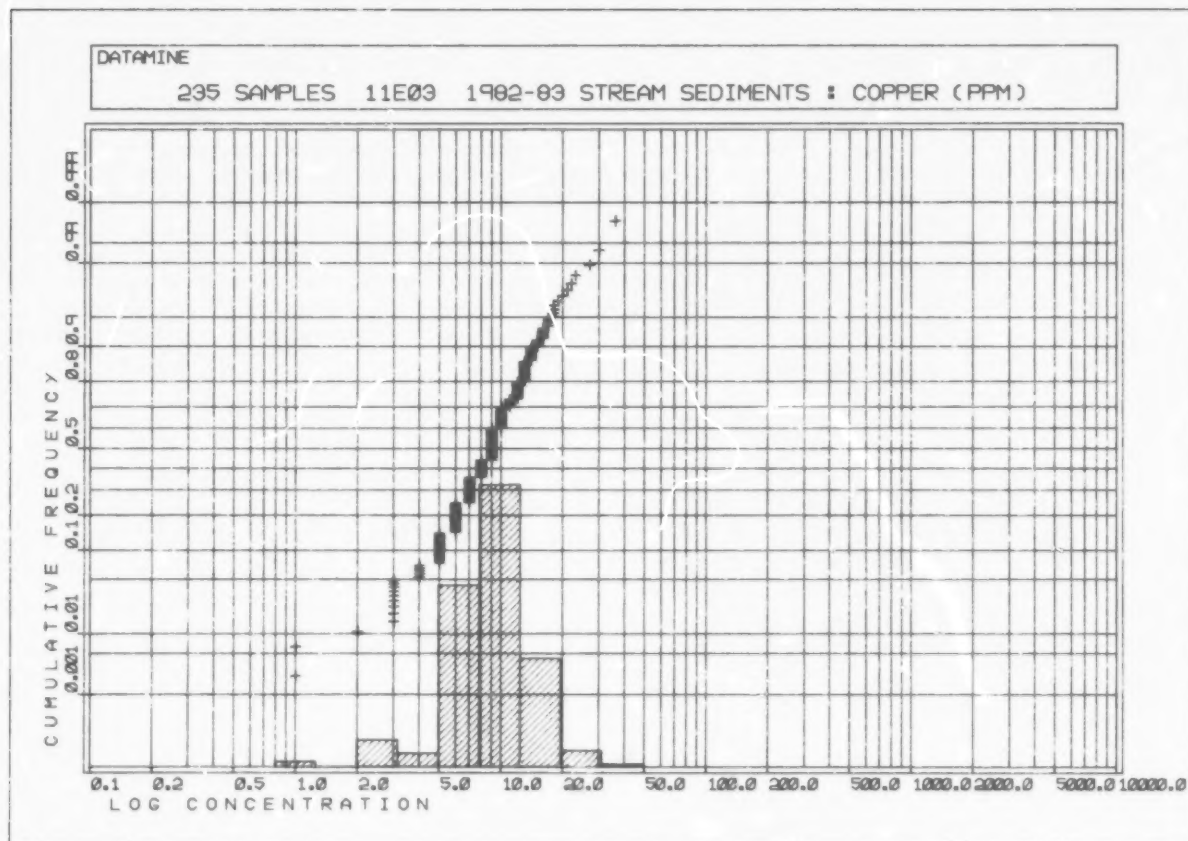


Figure 3. An example of a Datamine software cumulative frequency histogram for all the data points of the 1982-83 stream sediment survey contained within NTS sheet 11E/03.

MacDonald and Y. Brown; Nova Scotia Department of Mines and Energy, Report 88-3, p. 152-156.

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Rogers, P. J. and MacDonald, M. A.
1985: Regional geochemical surveys; in Mines and Minerals Branch, Report of Activities 1984, eds. K. A. Mills and J. L. Bates; Nova Scotia Department of Mines and Energy, Report 85-1, p. 55-67.

**RARE-EARTH-ELEMENT VARIABILITY IN GANGUE MINERALOGY
OF MEGUMA-HOSTED AURIFEROUS QUARTZ VEINS, NOVA
SCOTIA: POSSIBLE CONSEQUENCE OF UNMIXING OF
 $H_2O-CO_2-NaCl-CH_4$ FLUIDS (?)¹**

D. J. Kontak and P. K. Smith

Auriferous quartz veins in the metatubiditic Lower Paleozoic Meguma Group of southern Nova Scotia contain a diverse assemblage of gangue minerals. For example, in addition to quartz, native gold and sulphides, there occurs plag, Kf, tour, carb, chl, bt, ma, gar, apatite, amph, epdt, sch and andalusite, albeit in highly variable quantities. Paragenetically, an early stage of Ca-rich plag (An_{30-70})-tour ($sch_{50}-drv_{50}$)-bt ($mg=0.50\pm0.05$)-gar± sulphides is overprinted by a later hypogene assemblage of alb-ms-chl-sph-carb-sch±sulphides ($\pm Au$). Stage 1 is constrained by garnet-biotite geothermometry at ca. 475°C, while the latter stage is considered to have formed at 300±50°C (O isotopes, fluid inclusions). Fluid inclusion studies indicate the vein-forming fluid was a mixed $H_2O-CO_2-CH_4$ ($XCO_2=0.10\pm0.05$) brine with 4-6 wt.% equivalent NaCl (+Ca, K, Fe, Mg). Evidence of fluid unmixing is present in most specimens examined.

We have analyzed plag, chl, bt, apatite and carb from quartz veins in a variety of gold deposits for trace elements, including the REEs. Although major element chemistry of the minerals is remarkably uniform within a deposit, the trace and REE element chemistry is highly variable. For example, chondrite-normalized REE profiles (CNRP) for plag and chl from Beaver Dam show a 100 fold range with fractionation ($(La/Lu)_N$) minor (5-2) for plag but extreme (50-5) for chl. Normalized values of other trace elements (Rb, Sr, Ba, Li, Pb, Y, Li, Cs) show <10 fold maximum variation which does not correlate with the CNRPs. Similarly, a large variation in CNRPs for carb from 9 deposits is observed with variable fractionation ($(La/Lu)_N=<1>$) and chondritic abundances ($\geq 10x$) within and between deposits. Again, other trace elements do not show obvious correlations. However, we do note that coexisting vein phases (e.g. bt-plag) give comparable CNRPs indicating that locally equilibrium conditions prevailed between mineral phases and that the fluid was of uniform composition with respect to the REEs.

The CNRPs for the vein minerals contrast markedly to the shale-like CNRP for the Meguma Group host rocks which remain constant regardless of intensity of alteration types (e.g. sulphide, phyllic, silicification). This variation of CNRPs between wall rock and vein minerals contrasts with what is generally observed in granite-hosted vein mineralization. For example, vein (alb, tripelite, clay) and greisen (ms) minerals at the East Kemptville tin deposit mimic closely the CNRP of the host leucogranite.

Possible explanations for the observed variability of the CNRPs of the gangue minerals in the gold veins include: (1) variable mixing of two (or more) fluids with contrasting absolute REE contents; (2) variable contamination of wall rock by a single, homogeneous (with respect to REEs) fluid; and (3) unmixing of the ore-forming fluid due to H_2O-CO_2

¹ Paper presented at the Atlantic Geoscience Society Colloquium on Current Research in the Atlantic Provinces, Amherst, Nova Scotia, February 3-4, 1989.

immiscibility. The third possibility is considered the most viable considering the known temperature constraints for the mineral paragenesis, uniform isotopic (O, C, S) compositions and vein minerals, fluid inclusion thermometric measurements and leachate analyses, and constant CNRPs for fresh and altered wall rocks. In addition, the experimental and empirical observations that LREEs and HREEs are preferentially partitioned by Cl and CO₂ complexes, respectively, would be consistent with the observations noted above.

FLUID INCLUSION STUDIES OF QUARTZ VEIN POLYTYPES FROM THE BEAVER DAM AND CARIBOU GOLD DEPOSITS, MEGUMA ZONE, NOVA SCOTIA: EVIDENCE FOR A SINGLE VEIN-FORMING EVENT¹

D. J. Kontak and P. K. Smith

There have been numerous theories advanced for the genesis of the auriferous quartz veins hosted by the Lower Paleozoic Meguma Group of southern Nova Scotia. In almost all models the veins have been considered to represent multiple episodes of vein injection which collectively lasted for considerable time because of the highly variable states of strain presently observed (e.g. early folded bedding parallel vein *versus* late ac vein). We have interpreted the veins as representing a single hydrothermal event, the consequence of fluid penetration into a subvertical shear regime at ca. 370 Ma; the differential states of strain within individual quartz veins merely reflect relative timing of vein formation (i.e. highly strained early *versus* low strain late). One way to test this "single-vein forming event" model is to examine nature of the vein-forming fluid as preserved in fluid inclusions - a single population of fluid inclusions would at least corroborate the model suggested.

Petrographic examination and thermometric measurements (approx. 2000 to date) of fluid inclusions from quartz and carbonate material from all vein types (bp, ac, en echelon, bull-crosscutting) in the Beaver Dam and Caribou deposits reveal very uniform features for all samples. The dominant fluid inclusion type consists of a mixed $H_2O-CO_2-CH_4$ brine with a uniform composition of $XCO_2 = 0.10 \pm 0.05$, $XCH_4 = <0.05$ and wt. % equivalent NaCl = <10. The minor but persistent presence of vapor-rich CO_2 inclusions and low salinity (i.e. <10 wt. % equiv. NaCl) aqueous-type inclusions is interpreted to indicate that incipient unmixing occurred during vein formation at both deposits. The only difference noted in thermometric data for the two areas is in final T_h which is $300 \pm 20^\circ C$ for Beaver Dam and $275 \pm 10^\circ C$ for Caribou.

Analyses of leachates (N=18) from ultrapure quartz separates from all vein types at the Beaver Dam deposit give exceptionally uniform results (cationic concentrations: $Na = 0.511 \pm 0.049$, $Ca = 0.225 \pm 0.108$, $K = 0.021 \pm 0.004$, $Mg = 0.0058 \pm 0.0034$, $Fe = 0.0009 \pm 0.0002$). These data are consistent with the fluid inclusion observations noted above which indicate the presence of a single fluid inclusion population and, hence, a common fluid chemistry.

The fluid inclusion data for the two deposits are interpreted to indicate that all vein types formed from a single, homogeneous fluid which was focused into structurally favourable sites during one hydrothermal event. The variability of inclusions reflects incipient unmixing of this $H_2O-CO_2-CH_4$ fluid as a result of P and T changes. The data do not support models invoking multiple generations of veins related to different fluids. An important extension of this study is that auriferous *versus* barren veins apparently have the same fluid inclusion population.

¹ Abstract of poster presented at the Atlantic Geoscience Society Colloquium on Current Research in the Atlantic Provinces, Amherst, Nova Scotia, February 3-4, 1989.

GOLD ENRICHMENT IN THE SOUTH MOUNTAIN BATHOLITH, NOVA SCOTIA¹

M. A. MacDonald and G. A. O'Reilly

Elevated values of gold (89 ppb - 10.94 ppm) are reported from seven locations within the South Mountain Batholith of southwestern Nova Scotia. These include: 525 ppb Au in a pyrite-arsenopyrite bearing quartz-greisen vein system at Sandwich Point; 89 ppb Au in a silicified (quartz and amethyst) and brecciated pyrite bearing fault zone from Roachs Pond; 2010 ppb Au in an arsenopyrite-pyrite bearing quartz vein/albitite zone near Upper New Cornwall; 525 ppb Au in a wolframite-scheelite-chalcopyrite-molybdenite (+ unidentified bismuth mineral) bearing quartz vein from Big Indian Lake; 690 ppb Au from a quartz-muscovite-tourmaline-molybdenite bearing greisen zone at Inglisville; 2035 ppb Au in a chalcopyrite-galena-sphalerite-pyrite-arsenopyrite bearing quartz vein from a fault zone near Little Toboatic Lake; and 10.94 ppm Au from a K-feldspathized granite porphyry near Westfield. This enrichment in Au is significant when compared to either the 'Clarke Index-I' value for crustal rocks (4 ppb Au) or the relatively unaltered rocks of the SMB (av. 5.9 ppb Au, N=422).

All occurrences except Roachs Pond are proximal to a granite-metasediment contact and have associated metasomatic alteration (e.g. greisenization, albitization). A model is proposed in which granitic rocks are the source of heat, aqueous fluids and 'granophile' elements (e.g. F, B, W, Sn, Mo, Cu, Pb, Zn, $\pm$ Au, Ag). Meguma Group metasediments and underlying basement rocks provide aqueous fluids and Au, Ag, As, Cu, Pb, Zn, Bi and Sb. The contact acts as an impermeable cap, thus providing a locus for fluids and deposition of polymetallic minerals. The Au enrichment in the Roachs Pond fault zone is associated with successive periods of silicification and brecciation and may represent another mode of occurrence.

¹ Paper presented at the Atlantic Geoscience Society Colloquium on Current Research, in the Atlantic Provinces, Amherst, Nova Scotia, February 3-4, 1989.

LITHOGEOCHEMICAL VARIATION IN THE GRANODIORITE AND BIOTITE MONZOGRAHITE OF THE SOUTH MOUNTAIN BATHOLITH, NOVA SCOTIA¹

R. Horne, M. Corey, L. Ham and M. MacDonald

The South Mountain Batholith is a large composite intrusion consisting of several leucomonzogranite - leucogranite (biotite-muscovite bearing) plutons intruding an envelope of predominantly biotite monzogranite - granodiorite (biotite only). The similar textural and modal mineralogy of the envelope rocks makes separation of these rocks difficult. Thus, a detailed geochemical study was undertaken to assess the elemental variations within the granitic rocks of the envelope.

Contouring of geochemical data indicates previously unrecognized systematic chemical variations within the envelope rocks. Using the observed geochemical variations and known geological boundaries the data have been grouped geographically. Final groupings are based on both absolute contents and variation trends, the latter of which reflect (i) normally zoned (relatively mafic borders), (ii) reversely zoned and (iii) unzoned areas. The distinction of these groups has facilitated the interpretation and modification of geological boundaries previously based on bedrock mapping. We consider these groups to represent separate intrusive suites.

Binary plots of the geochemical data and normative mineralogy collectively indicate single uniform trends with variable intragroup ranges for the respective x and y parameters. This systematic behavior of the data suggests that all the chemical variation can be explained in terms of crystal fractionation of the observed mineral phases. However, statistical treatment of the data using discriminant function analysis indicates that near perfect separation of the groups exists (!). This indicates the existence of distinct chemical differences among the groups that are not recognized using conventional Harker-type diagrams.

Preliminary interpretation of the data suggests that the envelope rocks consist of discrete intrusive suites which have geochemically distinct signatures. More speculative is the fact that the geochemical distinctions among the groups may ultimately be reflecting different source regions (?).

¹ Paper presented at the Atlantic Geoscience Society Colloquium on Current Research in the Atlantic Provinces, Amherst, Nova Scotia, February 3-4, 1989.

THE MINERALOGY, PETROLOGY AND GEOCHEMISTRY OF THE HALFWAY COVE-QUEENSPORT PLUTON, NOVA SCOTIA, CANADA¹

L. J. Ham

The Halfway Cove-Queensport pluton (HCQP) of eastern Nova Scotia is a moderately deformed, post-Acadian granitoid intrusion that was emplaced into Meguma Group metasedimentary rocks by passive stoping, with some degree of forceful emplacement. Deformation features (C-S fabrics) occur in the northern and southern parts of the body. The peraluminous pluton is composed primarily of monzogranite, with minor granodiorite, with five rock units recognized by textural and mineralogical characteristics (HCQP1, HCQP1A, HCQP2, HCQP3, HCQP4). There are minor late-stage intrusions of aplite, pegmatite and leucogranite.

All rocks, except the late-stage intrusions, contain quartz, alkali feldspar, plagioclase, muscovite and biotite. Garnet and apatite occur in trace amounts. Cordierite is not present, contrasting with other peraluminous granitoid bodies of the Meguma Zone (e.g. SMB and MB) where cordierite is common. The presence of garnet and muscovite, both of presumed magmatic origin, constrains the pressure of crystallization to between 3 and 4 kbars (10.5-14 km).

Major element compositions resemble those of other granitoid plutons of central and eastern Nova Scotia, with lower FeO_t , TiO_2 and higher Al_2O_3 , P_2O_5 and normative corundum than the SMB. The least evolved units of the HCQP, however, are chemically more similar to rocks of the SMB. A well-defined chemical break between the two least evolved units (HCQP1 and HCQP1A) and the three more evolved units (HCQP2, HCQP3 and HCQP4) suggests that processes such as fractional crystallization, assimilation and melting of heterogeneous sources may have contributed to the overall chemical variation in the HCQP. REE patterns of unit HCQP1 resemble granodiorite patterns of the SMB, but patterns of units HCQP2 and HCQP4 are different from both HCQP1 and the SMB. Field, petrographic and geochemical characteristics suggest that the economic potential of the HCQP is limited.

¹ Paper presented at the Atlantic Geoscience Society Colloquium on Current Research in the Atlantic Provinces, Amherst, Nova Scotia, February 3-4, 1989.

A COMPARISON OF THE CLAST COMPOSITION AND GEOCHEMISTRY OF GRANITE TILLS TO UNDERLYING BEDROCK IN THE HALIFAX PLUTON, CENTRAL NOVA SCOTIA¹

*R. M. Graves, M. A. MacDonald, P. W. Finck
and F. J. Boner*

Granite tills overlying the Halifax Pluton (HP) are primarily locally derived and have renewal distances varying from 100 - 500 m. A program of till sampling and clast identification determined that regional granite clast patterns in these tills accurately reflect the underlying HP bedrock. The granite clast distribution within these tills can be used to enhance bedrock mapping in areas of limited outcrop.

The strongly compatible and incompatible behaviour of trace elements within the granitic rocks of the Halifax Pluton is indicative of a comagmatic suite. This elemental behaviour is not reflected in tills derived from each of the granitic phases. Postglacial weathering, contamination from up-ice rock types and bedrock mineralization have altered the primary 'bedrock' trends such that elemental differences among the tills have been destroyed. The similarity of chemical composition precludes the need to determine anomaly threshold levels for individual granite tills.

Chalcophile elements are neither concentrated nor depleted in bedrock of the HP but remain constant with respect to monzogranite type. Till anomalies involving these elements do not result from inherently high levels in the parent monzogranites but reflect up-ice bedrock mineralization.

¹ Paper presented at the Eighth International Symposium on Prospecting in Areas of Glaciated Terrain, Halifax, Nova Scotia, August 28 - September 3, 1988; in *Prospecting in Areas of Glaciated Terrain - 1988, Proceedings of a Symposium* sponsored by The Geology Division of CIM, Halifax, Nova Scotia, August 28 - September 3, 1988; eds. D. R. MacDonald and K. A. Mills, p. 21-39.

GLACIAL DISPERSAL IN NOVA SCOTIA: A ZONAL CONCEPT¹

R. R. Stea, R. G. Turner, P. W. Finck and R. M. Graves

A complex pattern of ice flows was imprinted on the landscape of Nova Scotia by the interplay of external and local ice divides. Four major Wisconsinan ice flow events (phases 1-4) have been defined. The shape and magnitude of dispersal trains in Nova Scotia are a result of the net effect of these ice flow events. The migration of ice divides during the Wisconsinan Stage from areas north of Nova Scotia to local areas produced a series of zones, areas with distinct dispersal trends defined by a pattern of mapped ice flow features. Dispersal studies in the zones confirm that the pattern of mapped ice flow features that were used to define the zones are mirrored by the shape of the dispersal trains. Topography and ice dynamics of the various glaciers controlled the deposition and composition of till units during the successive ice flow phases. Tills produced by the later phases (3 and 4) are characterized by dominance of clast over matrix modes and relatively local dispersal. Tills produced during the earlier phases (1 and 2) tend to be dominated by matrix modes and have greater percentages of far-travelled components.

¹ Paper presented at the Eighth International Symposium on Prospecting in Areas of Glaciated Terrain, Halifax, Nova Scotia, August 28 - September 3, 1988; in *Prospecting in Areas of Glaciated Terrain - 1988, Proceedings of a Symposium sponsored by the Geology Division of CIM, Halifax, Nova Scotia, August 28 - September 3, 1988*; eds. D. R. MacDonald and K. A. Mills, p. 57-79.

VARIATION IN DRUMLIN ORIENTATION, FORM AND STRATIGRAPHY RELATING TO SUCCESSIVE ICE FLOWS IN SOUTHERN AND CENTRAL NOVA SCOTIA¹

R. R. Stea and Y. Brown

A strong correspondence exists between striation and drumlin long axes trends in Nova Scotia. The variation in striation trends is largely due to successive ice flow events which inscribed many outcrops with sets of superimposed striations that can be correlated over broad areas of Nova Scotia. A type of drumlin in the Nova Scotia fields is the "lobate" or "reoriented" drumlin which is a form with two principal axes parallel to ice movements established by striations and dispersal of distinctive erratics. The internal structure of Nova Scotia drumlins is generally a layer cake of till sheets. The most common situation is a grey "core" till formed by a southeastward ice flow across grey metasedimentary bedrock and a distinctly red "mantle" till formed by phases of southward to southwestward ice flow. Drumlins in the Yarmouth Field of southern Nova Scotia exhibit the greatest number of stacked units capped by a coarse textured till that represents deposition by a late stage ice mass centered inland.

Nova Scotia drumlins appear to have a multi-phase origin. The first and major drumlin-forming ice flow phase was southeastward. Nucleating agents for initiation of these drumlins may have been pre-existing tills or waterlain deposits. Individual and lobate drumlin axes imply a late, southward drumlin-forming ice flow phase parallel to the inferred ice flow trend for the mantle till units based on clast provenance. Some of these drumlins nucleated from pre-existing southeast-trending forms.

¹ Paper presented at the Atlantic Geoscience Society Colloquium on Current Research in the Atlantic Provinces, Amherst, Nova Scotia, February 3-4, 1989.

NORTHERN APPALACHIAN TERRANES AND THEIR ACCRETIONARY HISTORY¹

J. D. Keppie

A revised terrane map of the northern Appalachians shows the following from northwest to southeast: (i) North American Terrane made up of Grenvillian basement overlain by Late Precambrian-Ordovician miogeocline and Ordovician foredeep; (ii) continental rise and oceanic lithosphere terranes thrust over North America; (iii) diverse volcanic arc, ocean and microcontinental terranes representing the vestiges of Iapetus; (iv) diverse Precambrian terranes overlain by platformal Cambro-Ordovician rocks with an Atlantic fauna defining the Avalon Composite Terrane; and (v) Cambro-Ordovician turbidites of the Meguma Terrane.

The accretionary history of these terranes shows the following sequence: (a) Late Precambrian amalgamation of the Avalon Composite Terrane during the Cadomian Orogeny; (b) progressive oblique dextral convergence in the northwestern part of Iapetus between North America and the Ascot-Weedon-Notre Dame volcanic arc throughout the Ordovician; (c) progressive oblique sinistral convergence in the southeastern part of Iapetus beneath the Bronson Hill-La Poile volcanic arc complex throughout the Ordovician, Silurian and early Devonian led to closure of Iapetus and sinistral emplacement of the Avalon Composite Terrane along a deep vertical fault (Dover-Turtle Head Fault); (d) progressive oblique dextral closure of the Theic Ocean between Avalonia and Gondwana leading to accretion of the Meguma Terrane by earliest Devonian and culminating in progressive continent-continent collision throughout the Devonian, Carboniferous and early Permian.

¹ Presented at the 23rd Annual Meeting, Northeastern Section, The Geological Society of America, Portland, Maine, March 10-12, 1988; in *Abstracts with Programs 1988*, v. 20, no. 1, p. 30.

METALLOTECTONIC ANALYSIS OF THE CANADIAN APPALACHIANS¹

J. D. Keppie

The northern Appalachians may be subdivided into the following terranes (from northwest to southeast) associated with characteristic mineral deposits:

(i) North American terrane consisting on its eastern side of Grenvillian basement overlain by a Late Precambrian-Ordovician miogeocline containing Nb in rift-related alkaline intrusives, remobilized sedimentary Cu+Mo+Ag in Late Precambrian-Cambrian rift sediments, and Mississippi Valley type Zn deposits in Lower Ordovician platformal limestone; in turn overlain by an Ordovician foredeep;

(ii) Hydrothermal Cu-Zn-Ag veins associated with tholeiitic volcanics in the continental rise terranes that have been thrust over the North American terrane;

(iii) Late Cambrian-Early Ordovician ophiolitic terranes typically containing chromite and asbestos in the ultramafic rocks, Cu+Zn(+Ag+Pb+Au) veins and massive sulphide deposits in the overlying tholeiitic volcanic rocks, and metamorphic/hydrothermal Sb+Mo+Au+Cu-Pb-Zn quartz veins produced during regional metamorphism;

(iv) Ordovician volcanic arc and rifted arc terranes which are host to Cu-Zn-Pb+Au+Ag+Sb massive sulphide deposits;

(v) Precambrian Avalon composite terrane which contains Pb-Zn-Cu-W skarns in Helikian metasediments, Zn-Cu-Pb+Au+Ag massive sulphides in Late Precambrian rifted volcanic arc rocks and in associated Cu-Mo porphyries.

These terranes are overstepped by Silurian-Devonian-Carboniferous sequences, the latter containing Cu-Zn-Ba mineralization in Viséan limestones. Devonian (-Carboniferous) plutonism is also widespread across the entire Appalachians, and is associated with polymetallic Sn-W-U+Mo+Sb+Bi+F+Be+Li+Cu+Au+Ag+Cu+Pb+Zn mineralization.

¹ Presented at the IGCP, IUGS, UNESCO International Conference, Terranes in the Variscan Belt of France and Western Europe, Montpellier, France, August 26-31, 1988.

Also presented at the Eighth International Conference on Basement Tectonics, Butte, Montana, August 8-12, 1988; in Eighth International Conference on Basement Tectonics, Characterization and Comparison of Precambrian through Mesozoic Continental Margins, International Basement Tectonics Association, Inc., p. 27.

TERRANES IN CIRCUM-ATLANTIC PALEOZOIC OROGENS: AN INTRODUCTION¹

J. D. Keppie

The Map of Terranes in the Circum-Atlantic Paleozoic Orogens depicts the terranes on a Triassic palinspastic reconstruction i.e. a closed Iapetus. The projection is a transverse Mercator projection with the Equator along the axis of Iapetus. The terranes are categorized in terms of tectonic affinity: cratonic or oceanic magmatic arc complexes, oceanic lithosphere and sequences, continental and metamorphic rocks of uncertain affinities. The ages of identified terranes range from circa 700-250 Ma. Late Precambrian terranes are included because many of the orogens in which they occur were still active in the earliest Paleozoic. The Terrane Map also shows overstepping sequences and post-accretionary stitching plutons with ages where known, and the age and nature of Precambrian basement. This map provides the base for the various thematic maps, such as tectonics, metamorphism, structure, igneous, metallogeny, stratigraphy and paleontology. This map and the various thematic maps will also provide the factual basis for a tectonic analysis of the Circum-Atlantic Orogens and palinspastic reconstructions. Future research on the extension of the exposed terrane boundaries beneath the overstepping sequences and at depth, and paleomagnetism of individual terranes should provide further constraints upon models for the evolution of the Circum-Atlantic Orogens.

Several regional trends may be identified. As might be expected, the major cratonic terranes and their miogeoclines are structurally separated from the magmatic arc and oceanic terranes in the internal and uppermost structural parts of the various orogens. Most oceanic terranes appear to represent small ocean basins rather than fragments of the main Iapetus Ocean. The late Precambrian terranes are limited to the southeastern regions south of Baltica. The presence of Grenvillian aged basement in southern Baltica suggests a net component of sinistral displacement along the Appalashian-Caledonide Orogen. Most of the identified Paleozoic, magmatic arc and oceanic terranes appear to have formed during Cambro-Ordovician times, with relatively few terranes formed during the Silurian-Carboniferous. This is consistent with the transition from an Iapetus Ocean with passive to active margins during the Early Paleozoic. A palinspastic model will be presented.

¹ Presented at the IGCP, IUGS, UNESCO International Conference, Terranes in the Variscan Belt of France and Western Europe, Montpellier, France, August 26-31, 1988.

LATE PRECAMBRIAN-PALEOZOIC TECTONOSTRATIGRAPHIC TERRANES IN THE CIRCUM-ATLANTIC, PHANEROZOIC OROGENS: A 1:5,000,000 COMPILATION MAP¹

J. D. Keppie and R. D. Dallmeyer²

A map of the Late Precambrian-Paleozoic terranes within the various circum-Atlantic Phanerozoic orogens has been prepared in association with I.G.C.P. Project 233. The base map is at a scale of 1:5,000,000 and represents a Triassic palinspastic reconstruction of the closed Atlantic Ocean. The base map is a transverse Mercator projection with the Equator entered along the axis of the closed Atlantic. The terranes are categorized according to their age (700-250 Ma; coded by color density) and seven possible palinspastic origins (coded by contrasting color and/or ornamentation): 1) autochthonous sequences; 2) imbricated basement/miogeocline; 3) cratonic magmatic arc complex; 4) oceanic magmatic arc complex; 5) oceanic lithosphere; 6) oceanic sedimentary/volcanic sequences; and 7) continental "rift-facies" sequences of uncertain significance. Also shown are post-accretionary plutons and overstep sequences (color coded and labelled with geologic age ranges). Schematic accretionary diagrams have been prepared for selected segments of the various orogens and they are positioned along the map borders.

The major cratonic terranes and their associated miogeoclinal sequences within the circum-Atlantic orogens are structurally separated from the various magmatic arc and oceanic terranes which occur in interior and/or uppermost tectonic settings. The Late Precambrian terranes are limited to southeastern segments of the map and their accretional history appears to have overlapped opening of Iapetus. Most of the Paleozoic magmatic arc and oceanic terranes appear to have formed during the Cambrian-Ordovician with relatively few terranes developing during the Silurian-Carboniferous. Most oceanic terranes appear to represent small ocean basins rather than vestiges of the main Iapetus tract.

¹ Presented at the IGCP, IUGS, UNESCO International Conference, Terranes in the Variscan Belt of France and Western Europe, Montpellier, France, August 26-31, 1988.

² Department of Geology, University of Georgia, Athens, Georgia.

PALYNOSTRATIGRAPHY OF LOWER CARBONIFEROUS (TOURNAISIAN) ROCKS OF NOVA SCOTIA¹

J. Utting², J. D. Keppie and P. S. Giles

Four palynological assemblage zones and two subzones may be recognized in Lower Carboniferous Tournaisian (Tn2 and Tn3) rocks of Nova Scotia. Probable ages have been established by correlating with the spore zones of Western Europe.

Assemblages from the lower member and lower middle member of the Horton Bluff Formation are of late Tn2 to early Tn3 age, from the upper middle and upper member of the Horton Bluff Formation and the Cheverie Formation of early to mid Tn3 age, and from the Wilkie Brook Formation of late Tn3 age. part of an unnamed formation lying stratigraphically below the Horton Bluff Formation is of Tn2 age. The hiatus between the Wilkie Brook and the overlying Windsor Group is probably slight (part of the early to middle Viséan), or it may, in some places, be non-existent.

Based on palynological data the oil shales of the Rights River Formation (Antigonish Basin) and the Albert Formation of New Brunswick are of similar age to the lower and lower middle members of the Horton Bluff Formation in the type area (late Tn2 to early Tn3).

The Thermal Alteration Index of the Horton Group throughout the study area varies, on a five point scale, from a low of 2- to a high of 3+. This suggests that there was a potential for liquid hydrocarbon generation in the areas with low thermal maturity e.g. southwest Windsor basin and northern Antigonish basin, but in areas where values are higher (3 to 3+), the potential was for condensate and dry gas generation.

1 Paper presented at the GAC, MAC, CSPG Joint Annual Meeting, St. John's, Newfoundland, May 23-25, 1988; *in* Program with Abstracts, v. 13, p. A128.

2 Institute of Sedimentary and Petroleum Geology, Geological Survey of Canada, Alberta T2L 2A7

PRECIOUS METAL EXPLORATION USING THE CATCHMENT BASIN MODEL OF LAKE SEDIMENT GEOCHEMISTRY¹

P. J. Rogers

Regional centre-lake bottom sediment geochemical surveys in Nova Scotia, as in the rest of Canada, have been widely used as a cost effective exploration tool. Lake sediments are perhaps unparalleled in their application to regional geochemical exploration as a means of rapidly covering and thereby assessing and identifying areas for follow-up study. In the early 1980s increasing interest in precious metal exploration in Canada has once again focused attention on centre-lake bottom sampling as an exploration medium especially for Au. Archived samples from an original 1977-78 Nova Scotia lake sediment survey were reanalyzed for Au and other elements (Rogers et al., 1985). The reanalysis produced new analytical data with numerous Au anomalies in the Meguma Zone, some of which are related to known gold deposits with others having a spatial relationship to granitoid rocks.

¹ Poster presented at Prospectors and Developers Association of Canada Annual Meeting, Toronto, March, 1988.

GOLD IN LAKE SEDIMENTS: IMPLICATIONS FOR PRECIOUS METAL EXPLORATION IN NOVA SCOTIA¹

P. J. Rogers

In 1977 and 1978 centre-lake bottom sediments in the Meguma Zone of southern Nova Scotia were sampled during a helicopter-borne survey. In 1984 these original samples were subsequently analyzed for gold. The results obtained indicate areas with anomalous gold values in the Meguma Zone, some of which are related to known gold deposits within Meguma Group metasedimentary rocks. Other anomalous areas underlain by metasedimentary and granitoid rocks cannot be linked to known Meguma Zone gold occurrences and therefore represent new areas for potential gold mineralization, especially within granitoid rocks. The scale and magnitude of these new gold anomalies merit follow-up exploration.

Lake sediment geochemical models for gold exploration are achieved using the lake catchment basin as the area of influence for the sample. Lake drainage systems act as dynamic and responsive collectors of geochemical information. Samples of gyttja, the organic-rich ooze, are representative of the composition of the lake catchment area. Input to lake catchment basins is dominated by surface weathering components with little groundwater interaction into the lake water column. Lake basins act as geochemical sinks trapping a mixture of chemical and mechanical weathering components. Scanning electron microscope studies of heavy mineral separates reveal numerous, discrete, particulate and sometimes unexpected mineral phases in the gyttja. The detection of free gold in Meguma Zone lake sediments underlines the important role that mechanical weathering can play in anomaly generation for lake sediment geochemical surveys. Detailed limnological studies performed on three Halifax Peninsula lakes with anomalous gold values detail the spatial and stratigraphic aspects of anomalies by coring the deepest sub-basins within the lakes.

The analytical data confirm lake sediments as reliable indicators for regional geochemical gold exploration. Detailed investigations of gold-bearing lake catchments confirm the presence of significant, reproducible gold anomalies. Borehole studies indicate strong coherent geochemical patterns within the lake catchments.

¹ Paper presented at the Eighth International Symposium on Prospecting in Areas of Glaciated Terrain, Halifax, Nova Scotia, August 28 - September 3, 1988; in *Prospecting in Areas of Glaciated Terrain - 1988, Proceedings of a Symposium sponsored by The Geology Division of CIM, Halifax, Nova Scotia, August 28 - September 3, 1988*; eds. D. R. MacDonald and K. A. Mills, p. 357-381.

CATCHMENT BASIN ANALYSIS OF REGIONAL STREAM SEDIMENT DATA: EXPLORATION AND TARGET SELECTION, COBEQUID HIGHLANDS, NOVA SCOTIA¹

P. J. Rogers, G. F. Bonham-Carter² and D. J. Ellwood²

The Cobequid Highlands area serves as a case example of how catchment basin analysis (CBA) can be used to refine background characterization and aid in interpreting regional geochemical data. A 1983 regional survey collected about 1,500 stream sediment and water samples at an average density of 1 sample per 2.5 km². Sediments were analyzed for Cu, Pb, Zn, Ag, Fe, Mn, Ni, Co, As, Hg, U and Mo, and waters for U, F and pH. Each stream sediment sample defines its own catchment basin as a numbered polygon which is the zone of influence for the sample. The polygon outline and geological maps were raster scanned to produce jointly registered images. A computer file was created describing location, chemical composition, geology, total area, mineralization and commercial assessment follow up work for each polygon.

Exploration target definition was approached in a variety of ways. Percentile scale coloured maps were made for each polygon with elemental values as themes filling catchment basins. Step-wise regression with areal proportions of mapped units as independent variables modelled geochemical background to produce residual maps. Factor score plots identified broad regional geochemical trends as distinct domains often related to large structural features and specific stratigraphic units. Further target selection included polygons containing known mineralization and detailed soil sampling grids. Anomalous catchments with "explained" patterns were removed to leave areas of unexplained patterns with exploration potential. Au and Cu-Pb-Zn targets are identified in Carboniferous sedimentary basins and contact areas of Devonian-Carboniferous volcanics and granites.

¹ Abstract of poster presented at the Colloquium on "Statistical Applications in the Earth Sciences", Geological Survey of Canada, Ottawa, Ontario, November 14-16, 1988.

² Geological Survey of Canada, 801 Booth St., Ottawa, Ont., K1A 0E8

REGIONAL STREAM SEDIMENT GEOCHEMISTRY AND EXPLORATION OF A MATURE AREA: TARGET SELECTION BY CATCHMENT BASIN ANALYSIS, COBEQUID HIGHLANDS, NOVA SCOTIA¹

P. J. Rogers, G. F. Bonham-Carter² and D. J. Ellwood²

A 1983 regional geochemical exploration program collected about 1,500 stream sediment and water samples in the Cobequid Highlands. The area has been extensively prospected on an intermittent basis since 1960. Catchment basin analysis (CBA) as applied to mineral exploration in this "mature" area aids in anomaly recognition and as a means of integrating bedrock geology, topographic and drainage data with geochemical, geophysical and remotely sensed data (Bonham-Carter et al., 1987). Regression experiments show that a large proportion of the variance in the data set can be explained by predicting the levels of a geochemical element for the 65 mapped lithologic units. Each stream sediment sample collected defines its own catchment basin as a numbered polygon as the zone of influence for the sample. Exploration target definition was approached in a variety of ways using CBA on each polygon. Percentile scale coloured maps from an ink jet plotter were made for each polygon with the elemental value as the theme filling the catchment basin. Step-wise regression using areal proportions of mapped units as independent variables were used to model geochemical background and produce residual maps. Factor score plots identified broad regional geochemical trends distinct domains related to major structural features and stratigraphic units (Rogers et al., 1987). Target selection also included polygons containing mineralization and detailed soil sampling grids. Anomalous catchments as polygons with "explained" elemental patterns are removed from the analysis to leave areas of unsuspected exploration potential.

The Cobequid Highlands of northern Nova Scotia comprise an elongated area 160 by 50 km with a central core of Precambrian and Lower Paleozoic schists, gneisses, volcanics and sediments intruded by numerous Devonian-Carboniferous granitoids. The area is bounded by a major fault system and a large Carboniferous sedimentary basin. Known mineralization is found in various associations, including Cu-U sandstone hosted deposits, fault-related Mn deposits, poorly understood vein deposits containing precious metals, and polymetallic vein deposits. Late Wisconsinan glaciation deposited two main till types in four major ice movements. Stream and water samples were collected at an average density of 1 sample per 2.5 km² in fast-flowing hydraulic regimes. Sediments were analyzed for Cu, Pb, Zn, Ag, Fe, Mn, Ni, Co, As, Hg, U and Mo, and waters for U, F and pH. Field sampling strategy included some nested basins, so samples are not necessarily geochemically or statistically independent from one another. The polygon outline and geological maps were raster scanned to produce jointly registered images. A computer file was created describing location, chemical composition, geology, total area, mineralization and commercial assessment follow up work for each polygon of the defined catchment basins.

¹ Extended abstract presented at the GIS Symposium, Integrating Technology and Geoscience Applications, Denver, Colorado, September 26-30, 1988.

² Geological Survey of Canada, 601 Booth St., Ottawa, Ont., K1A 0E8

For the Cobequid Highlands data, between 25 to 65 per cent of the total variance can be solely attributed to areal proportions of mapped geological units. Scavenging in the secondary environment of certain elements by Fe and Mn oxides and hydroxides along with pH effects is also modelled by this approach. Regression analysis is used to model background effects for each element. After removal of variance due to catchment geology and scavenging, a residual map is plotted to enhance the definition of anomalous areas and improve target selection and avoid the investigation of spurious anomaly patterns especially for Fe-Mn-Ni-Co-As-Cu and Cu-Pb-Zn associations in this case. The first 3 principal components of the logarithms of the element data (explaining 64% of variance) are plotted as factor scores with each factor as one of 3 primary colours. These plots identify distinct geochemical domains related to regional structure and lithological units. Target selection was further refined by a consideration of the known metallogeny and previous commercial work which was compiled for each catchment basin and entered into the computer file for the numbered polygon. In this manner the 90th percentile values from each polygon were compared to anomalous soil values or known mineralization to identify "explained" anomalous values for each element.

The Cobequid Highlands area serves as a case example of how image analysis techniques using CBA can be used to refine background characterization and aid in the interpretation of regional geochemical survey data. Mineral exploration by CBA in a mature area results in enhanced target selection and previously unsuspected anomalous areas. New potentially mineralized lithologic settings are indicated for Au, Cu, Pb and Zn in Carboniferous sediments and contact areas of Devonian-Carboniferous volcanics and granites. CBA allows sampling of other databases such as airborne radiometric data and satellite imagery to facilitate application of Geographic Information Systems to exploration geochemistry.

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BIOLOGICAL AND GEOCHEMICAL SEDIMENTATION ALONG A pH GRADIENT IN SOLDIER LAKE, HALIFAX COUNTY, NOVA SCOTIA¹

J. G. Ogden, III² and P. J. Rogers

Soldier Lake is a dilute brown water lake near the Halifax International Airport which has been acidified by leachates from heavily pyritized slates exposed during construction activity at the airport. Concurrent highway development in the Soldier Lake catchment has created "borrow pits" in quartzite.

At present, there is an hydrogen ion gradient ranging from 0.7 $\mu\text{eq L}^{-1}$ (pH 6.2) to 66.1 $\mu\text{eq L}^{-1}$ (pH 4.2) at the Johnson River inlet to the lake and to 102.3 $\mu\text{eq L}^{-1}$ (pH 2.99) at the headwaters near the airport.

Mass balance studies indicate retention (and presumably deposition) of 33% of the aluminum, 63% of the organic carbon, and 85% of the iron entering the lake. Outlet pH values (4.6 = 25.1 $\mu\text{eq L}^{-1}$) imply neutralization of 38% of the hydrogen ions entering the lake.

Surficial sediment and overlying basal lake water samples show the existence of distinct geochemical and biostratigraphic domains along the pH gradient which have sampling implications for hydrogeochemical investigations.

¹ Paper presented at the International Groundwater Symposium on Hydrogeology of Cold and Temperate Climates and Hydrogeology of Mineralized Zones, Halifax, Nova Scotia, May 1-5, 1988; *in* Proceedings, ed. C. L. Lin, p. 202-210.

² Department of Biology, Dalhousie University, Halifax, N.S. B3H 4J1

SPATIAL DATA INTEGRATION OF LAKE SEDIMENT GEOCHEMISTRY, GEOLOGY AND GOLD OCCURRENCES, MEGUMA TERRANE, EASTERN NOVA SCOTIA¹

D. F. Wright², G. F. Bonham-Carter² and P. J. Rogers

Lake sediment geochemistry of 436 samples collected from the Meguma Terrane, eastern Nova Scotia, as studied using a spatial analysis system to evaluate and interpret distribution patterns of elements, and their relationship to the mapped geology and the location of known gold occurrences. Principal component analysis shows four main associations explaining a total of 70% of the total variance: (1) Zr, Rb, Ti, Li, Th, Nb, F; (2) Cu, Pb, Zn, As, Sb; (3) Au, W; and (4) Sn. The first association, similar to that found in other lake sediment studies in Ontario and Nova Scotia, suggests that a major control on lake sediment chemistry is the concentration of resistate minerals by mechanical processes. Regression experiments indicate that the bedrock geology and surficial geology have very little influence on the spatial patterns of the elements. This is in marked contrast to the strong bedrock control noted in other lake sediment studies and is probably related to the lack of significant geochemical differences between the bedrock units encountered in the study area. Gold in lake sediment is found to be an excellent predictor of gold mineralization, as are arsenic and tungsten, but to a lesser degree. A map of areas favourable for gold mineralization, based on a multi-element geochemical signature, shows several areas with a favourable geochemical response, but no reported mineral occurrences.

¹ Paper presented at the Eighth International Symposium on Prospecting in Areas of Glaciated Terrain, Halifax, Nova Scotia, August 28 - September 3, 1988; in *Prospecting in Areas of Glaciated Terrain - 1988, Proceedings of a Symposium* sponsored by the Geology Division of CIM, Halifax, Nova Scotia, August 28 - September 3, 1988, eds. D. R. MacDonald and K. A. Mills, p. 501-515.

² Mineral Resources Division, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8

HEAVY MINERALS AND SEDIMENT DISPERSAL TRENDS AS EXPLORATION TOOLS FOR POTENTIAL TIN AND GOLD PALEOPLACERS IN CARBONIFEROUS ROCKS, NOVA SCOTIA¹

R. J. Ryan, R. Turner, R. R. Stea and P. J. Rogers

Paleoplacers have long been known in the clastic Carboniferous strata of Atlantic Canada. The Gays River gold mine in Nova Scotia was a paleoplacer mine which operated in the late 1800s. Recent studies of heavy minerals in clastic sedimentary rocks, till and stream sediments from northern Nova Scotia have found cassiterite and wolframite to be common in all of the sampled media. The presence of these minerals in the various media provides an opportunity to study distribution of the minerals in clastic bedrock, till and stream sediments. Cassiterite and wolframite from the strata of the Cumberland Basin and associated tills and stream sediments are used to demonstrate the mechanics of transport and deposition of paleoplacers by low sinuosity streams during the Carboniferous. An understanding of sediment dispersal trends is essential to paleoplacer exploration as it defines large prospective areas and delineates channel morphology necessary to assess the extent of the paleoplacer deposit. The exploration model for Sn-W transport and deposition can be applied to Au in other areas of the Maritimes Basin where the Au paleoplacer potential is enhanced because of the direct input of basin fill material from Au enriched areas such as the Meguma Terrane.

¹ Paper presented at the Eighth International Symposium on Prospecting in Areas of Glaciated Terrain, Halifax, Nova Scotia, August 28 - September 3, 1988; in *Prospecting in Areas of Glaciated Terrain - 1988, Proceedings of a Symposium sponsored by The Geology Division of CIM, Halifax, Nova Scotia, August 28 - September 3, 1988*; eds. D. R. MacDonald and K. A. Mills, p. 41-56.

CARBONATE BUILDUPS IN THE LOWER CARBONIFEROUS HORTON AND WINDSOR GROUPS (LATE TOURNAISIAN - VISEAN) OF NOVA SCOTIA¹

R. C. Boehner

Carbonate buildups have been identified in most Carboniferous basins in an area extending 350 km from Mahone Bay to Sydney. They occur as marine bioherms, reef mounds or banks in the Windsor Group (70 localities), and one lacustrine algal - caliche lithoherm occurs in the underlying, nonmarine Horton Group. The buildup distribution and composition reflects the many factors linked with basin development, i.e. depositional environments, paleogeography and biota. The most numerous (40 localities), thickest and most laterally extensive buildups are banks of the Gays River Formation at the base of the Windsor Group (Major Cycle 1). These were strongly influenced by paleotopography and are localized near unconformities on basin margins. Younger buildups in Major Cycle 2 (25 loc.) and Major Cycles 3-5 (5 loc.), are less numerous but have an expanded distribution into a basinal setting, without any apparent substrate or paleotopographic control, as well as in the basin margin setting. The distribution pattern partly reflects the smoothed paleotopography accompanying basin infilling by MC 1 evaporites, and continued onlap of basin margins. An isolated mound form (10-50 m thick) with a thin, off mound facies (1-5 m) is characteristic of MC-1 and 2 buildups. This contrasts with MC-3 and 5 buildups (20 m) which are enveloped within the normal carbonate facies of similar thickness.

Although volumetrically subordinate to the regionally extensive carbonate members, the buildups are: (1) major sources of high grade limestone and dolostone for industry and agriculture, (2) hosts for base metal and celestite deposits and (3) potential hydrocarbon reservoirs

¹ Abstract of poster presented at the Atlantic Geoscience Society Colloquium on Current Research in the Atlantic Provinces, Amherst, Nova Scotia, February 3-4, 1989.

STRATIGRAPHIC DRILLING OF THE WINDSOR GROUP: THE ALTON GAS OCCURRENCE¹

D. C. Carter

The Alton (ALT-87-1) drillhole was located to examine the stratigraphy and structure of the Windsor Group evaporites in the north-central portion of the Shubenacadie Basin. The hole was spudded in Watering Brook Fm., Canso Group strata and the oldest formation penetrated was the A Subzone, Carrolls Corner Fm., Windsor Group. Top-of-salt (base-of-dissolution) was intersected at 404.87 m. The drillhole was terminated at 683.05 m due to an uncontrolled flow of natural gas into the well-bore.

The gas flow was controlled by an annular blow out preventer (BOP) and killed with a treated and weighted cement. This represents the first time that a hydrocarbon flow has been controlled and killed with this type of equipment on a diamond drill in eastern Canada and procedures developed are specific to this type of equipment.

The gas flow characteristics were evaluated, within the limits of the wireline coring equipment, prior to the kill operation.

¹ Paper presented at the Atlantic Geoscience Society Colloquium on Current Research in the Atlantic Provinces, Amherst, Nova Scotia, February 3-4, 1989.

CONTROLS ON BASIN-FILL PATTERNS WITHIN THE STELLARTON BASIN, NOVA SCOTIA¹

R. D. Naylor

The Stellarton Basin is a 6 by 18 km rhomb graben located between the Hollow and Cobequid Faults in central northern Nova Scotia. From the Westphalian B through D, over 2600 m of red and grey coal-bearing strata (the Stellarton Formation) were deposited as the graben opened. Basin-fill patterns within the Stellarton Basin varied largely in response to several interrelated factors, specifically: changes in the rate of tectonic subsidence, water levels, and regional versus local sediment supply. When subsidence rates and water levels within the basin were low, lakes developed near the basin center. These lakes were completely infilled by delta deposits that had a predominantly regional source area. When sediment supply became restricted, and subsidence rates remained low, poorly drained swamps and thick peat mires formed at the basin center. During periods when subsidence rates were high, water levels remained high and a lake was maintained over much of the basin floor. Delta deposits partly infilled this lake when sediment supply rate from regional sources was high. When regionally sourced sediment supply became restricted, swamp and mire deposits developed on abandoned delta plains near basin margins.

¹ Paper presented at the Atlantic Geoscience Society Colloquium on Current Research in the Atlantic Provinces, Amherst, Nova Scotia, February 3-4, 1989.

PICTOU COALFIELD: A CLASSIC STRIKE-SLIP LACUSTRINE BASIN¹

R. D. Naylor, W. D. Smith, G. M. Yeo² and R. Snow²

The late Westphalian Pictou Coalfield of northern Nova Scotia is restricted to a rhomb graben, between the right-step, en echelon terminations of the eastern Cobequid and Hollow faults. Detailed structural analysis shows that late Westphalian movement on these faults was dextral.

The first manifestation of this period of fault movement was northerly shedding of alluvial fan conglomerates and sandstones of the Westphalian B-C Cumberland Group. Progressive fault overlap resulted in formation and expansion of the graben, in which coal-bearing lacustrine shales and sandstones of the Westphalian C-D Stellarton Group were deposited disconformably on Cumberland and unconformably on older strata. These contrast with coeval sandstones, shales and limestones of the Pictou Group, deposited north of the graben by northerly flowing anastomosing rivers and in shallow lakes.

Graben infilling can be subdivided into three major phases. In the first, basin margin redbeds overlain by thick fine-grained grey basinal clastics reflect lacustrine transgression and slow, steady subsidence. Periodically, peat sequences, containing cyclic limnic, marsh, and forest swamp facies, prograded into the lake. Following an abrupt regression, the second phase was much like the first. In the third phase, lobate sandy deltas prograded increasingly into the basin. These reflect relatively rapid, episodic subsidence. Peat accumulations on abandoned delta lobes were in turn drowned by rising lake waters. Each phase or infill may be correlated with deformation events recognized in the boundary fault zones.

¹ Paper presented at the GAC, MAC, CSPG Joint Annual Meeting, St. John's, Newfoundland, May 23-25, 1988; in Program with Abstracts, v. 13, p. A90.

² Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8

OIL SHALES OF THE STELLARTON BASIN, NOVA SCOTIA, CANADA: STRATIGRAPHY, COMPOSITION, DEPOSITIONAL ENVIRONMENT, AND POTENTIAL USES¹

W. D. Smith, R. D. Naylor and W. D. Kalkreuth²

The fault-bounded Stellarton Basin of northern Nova Scotia contains the Province's largest oil shale resources (825×10^6 tonnes with 168×10^6 bbls of shale oil *in situ*). The oil shales belong to the 2600 m thick coal-bearing Stellarton Formation of Westphalian B-D age. A total of 60 oil shale beds, which are separated by sandstone, siltstone, claystone, and/or coal, occur within the formation. Individual beds thicken and thin laterally, average 5 m thick (one bed is up to 35 m thick), and are laterally continuous over 3-5 km. Near basin margins some of the oil shale beds are vertically and laterally transitional to coal.

Three lithologies, all silicate-rich (principally illite, quartz), comprise the oil shale beds, namely, fissile shale, cannel shale (massive oil shale) and boghead shale (stellartite). Cannel shales accumulated at or near lake margins while fissile shale and boghead shale formed under open lacustrine conditions.

Average hydrocarbon yields of 25 litres per tonne (l/t) or less, 40 l/t and 110 l/t are obtained from fissile shale, cannel shale and boghead shale, respectively. Total organic carbon (TOC) contents of fissile shale average 5 wt% and comprise algal debris and minor vitrinite and inertinite. Cannel shales are transitional to coal and contain up to 40 wt% TOC mostly as vitrinite and inertinite. Boghead shales average 19 wt% TOC mostly as telalginite. Combustion testing of cannel shale from one bed show them to be comparable to some currently produced Western Canadian coal generating 7800 BTUs/lb. Testing of boghead shale from 4 different beds gave values of only 150-4500 BTUs/lb.

Hydrocarbon yields of the oil shales show them to have yields too low for direct utilization when compared to higher yielding, but undeveloped, oil shales elsewhere (e.g. Green River, Rundle and Albert deposits). However, the ability to recognize distinct oil shale beds within sections separated by 3-5 km makes them useful for section correlation. The association of some oil shale beds with coal show them to be a useful guide for coal exploration as well.

¹ Paper presented at the Atlantic Geoscience Society Colloquium on Current Research in the Atlantic Provinces, Amherst, Nova Scotia, February 3-4, 1989.

² Geological Survey of Canada, 3303-33rd Street N.W., Calgary, Alberta T2L 2A7

PETROLOGY AND DEPOSITIONAL ENVIRONMENTS OF COALS AND ORGANIC-RICH SHALES FROM THE LATE CARBONIFEROUS PICTOU COALFIELD, NOVA SCOTIA¹

G. M. Yeo², W. Kalkreuth³, R. D. Naylor and W. D. Smith

The Pictou Coalfield is a coal- and oil shale-bearing, lacustrine basin developed in a synsedimentary rhomb graben.

In contrast with typical (fluvial basin) Appalachian coals, the intermediate rank Pictou coals are characterized by microbanding, low sulphur, and high ash, which increases toward the basin margins. Macroscopic appearance, previous microlithotype studies, and proportions of maceral groups (vitrinite > inertinite > liptinite) indicate a high degree of petrographic uniformity within seams, but the proportions of individual macerals vary considerably, reflecting environmental and diagenetic changes. Specific maceral ratios indicate cyclic development of wet forest swamp, fen, and limnic conditions in response to alternate flooding and drying trends during peat accumulation. Such coal facies variation within seams can be correlated laterally.

On the basis of macroscopic and petrographic features, three types of organic-rich shale can be recognized: (1) vitrinite and inertinite-rich cannel shale, commonly transitional to humic coal, (2) telalginite-rich boghead shale, and (3) lamalginite-rich shale. The maceral types reflect depositional environments. The cannel shales accumulated near lake margins, while the two types of oil shale were deposited under quiescent, offshore conditions.

¹ Paper presented at the GAC, MAC, CSFG Joint Annual Meeting, St. John's, Newfoundland, May 23-25, 1988; in Program with abstracts, v. 13, p. A137-138.

² Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8

³ Geological Survey of Canada, 3303-33rd Street N. W., Calgary, Alberta T2L 2A7

**PETROGRAPHY, ORGANIC GEOCHEMISTRY, AND
DEPOSITIONAL ENVIRONMENTS OF COAL AND OIL
SHALE FROM THE PICTOU COALFIELD,
NOVA SCOTIA, CANADA¹**

*W. Kalkreuth², R. Naylor, W. Smith,
J. Paul³, W. Puttmann⁴ and G. Yeo⁵*

The Pictou Coalfield is a coal- and oil shale-bearing lacustrine basin developed in a syndimentary rhomb graben. Deposition and diagenesis of the coals and oil shales was assessed by incident light microscopy (maceral and microlithotype analyses) and organic geochemistry (gas chromatography and mass spectroscopy).

The Pictou coals are characterized by microbanding, low sulphur, and ash contents which increase towards the basin margin. Maceral and microlithotype analyses for a number of seams indicate cyclic development of limnic, fen, and wet forest environments, reflecting alternating flooding and drying trends during peat accumulation. N-alkane distributions from the coal extracts indicate that terrestrial plant material was predominant. In the aromatic fraction, components such as dibenzofuran and fluorene are most likely derived from lignin during diagenesis.

Three types of organic-rich shales are recognized: 1) vitrinite- and inertinite-rich cannel shale, transitional to coal; 2) telalginite-rich boghead shale, and 3) lamalginite-rich shale. The cannel shales accumulated at and near lake margins, while the alginite-rich shales were deposited under open lacustrine conditions. The oil shale extracts show a predominance of short chain n-alkanes in the saturated fraction and a predominance of naphthalenes in the aromatic fraction. Biomarker ratios, such as pristane/phytan ratio, indicate a reducing milieu during deposition.

¹ Presented at the Geological Society of America 1988 Centennial Celebration, Denver, Colorado, October 31-November 3, 1988; in Abstracts with programs, v. 29, no. 7, p. A170.

² Geological Survey of Canada, 3303-33rd Street N. W., Calgary, Alberta T2L 2A7

³ Geologisches Institut der Universität Köln, Zulpicherstr. 49, 5 Köln, Germany

⁴ Lehrstuhl für Geologie, Geochemie, und Lagerstätten des Erdöls und der Kohle, Lochnerstr. 4-20, 51 Aachen, Germany

⁵ Geology Department, Acadia University, Wolfville, Nova Scotia B0P 1X0

PETROLOGY, ROCK EVAL AND FACIES ANALYSES OF THE MCLEOD COAL SEAM AND ASSOCIATED BEDS, PICTOU COALFIELD, NOVA SCOTIA, CANADA¹

J. Paul², W. Kalkreuth³, R. Naylor and W. Smith

Coals, cannel coals and oil shales of the McLeod sequence from two boreholes in the Pictou Coalfield, N.S., were analyzed using methods of organic petrology and organic geochemistry.

Petrographic composition was determined by maceral and microlithotype analyses. Within the McLeod coal seam, varying amounts of alginite, vitrinite, inertinite, and mineral matter indicate significant changes in the environment of deposition. High amounts of lamalginite and minerals, i.e. clay minerals and pyrite, at the base and top of the seam indicate a limnic depositional environment, whereas much dryer conditions are indicated for the middle portion of the seam by better tissue preservation, typical for a wet forest type of swamp. This was also confirmed by results from microlithotype analyses. In the oil shales the predominant maceral is alginite.

Coals, cannel coals and oil shales vary significantly in total organic carbon (TOC) values and hydrocarbon potentials. Parameters such as Hydrogen and Oxygen Indices and Hydrocarbon Potentials are in good agreement with results from petrographic analyses.

Methods of organic petrology and organic geochemistry define distinct types of organic matter in coals, cannel coals and oil shales which can be related to facies changes and environments of deposition. From the preliminary results it appears that these methods also can be applied regionally for stratigraphic correlations within sequence of rapid facies changes.

¹ Abstract of poster presented at the GAC, MAC, CSPG Joint Annual Meeting, St. John's, Newfoundland, May 23-25, 1988; *in* Program with abstracts, v. 13, p. A96.

² Geologisches Institut der Universität Köln, Zulpicherstr. 49, 5 Köln 1, Germany.

³ Geological Survey of Canada, 3303-33rd Street N. W., Calgary, Alberta T2L 2A7

APPENDIX I

NOVA SCOTIA DEPARTMENT OF MINES AND ENERGY

PUBLICATIONS AND MAPS

AVAILABLE FOR PURCHASE

PAPERS

- Paper 76-1 Structural Model for the Saddle Reef and Associated Veins in the Meguma Group, Nova Scotia, by J. D. Keppie, 34 pages, 2 maps. (\$3.00)
- Paper 76-2 Geological Data Collection in the Nova Scotia Department of Mines, by J. D. Keppie and A. K. Chatterjee, 15 pages. (\$0.50)
- Paper 76-3 Interpretation of P.P.I. Radar Imagery of Nova Scotia, by J. D. Keppie, 31 pages, 1 map. (\$1.25)
- Paper 76-4 Geology, Geochemistry and Mineral Occurrences of the Northeast Margaree River Drainage Basin in parts of Inverness and Victoria Counties, Cape Breton, Nova Scotia, by B. E. MacNabb, J. H. Fowler and T. G. N. Covert, 30 pages, 12 maps. (\$15.00)
- Paper 76-5 Guide to the Invertebrate Fauna of the Windsor Group in Atlantic Canada, by R. G. Moore and R. J. Ryan, 57 pages. (\$2.25)
- Paper 77-1 Tectonics of Southern Nova Scotia, by J. D. Keppie, 34 pages (Reprinted 1980). (\$3.00)
- Paper 77-3 Plate Tectonic Interpretation of Paleozoic World Maps (with Emphasis on Circum-Atlantic Orogens and Southern Nova Scotia), by J. D. Keppie, 45 pages (Reprinted 1982). (\$4.00) (Microfiche \$1.50)
- Paper 77-6 Sand and Gravel Resources of Pictou County, by J. H. Fowler and G. B. Dickie, 42 pages, 1 map. (\$4.00)
- Paper 77-7 Tungsten Mineralization in the Carbonate Rocks of the George River Group, Cape Breton Island, Nova Scotia, by A. K. Chatterjee, 26 pages. (\$3.50)
- Paper 78-1 Geology of the Ecum Secum Area, Halifax and Guysborough Counties, Nova Scotia, by D. McBride, 12 pages. (\$1.00)
- Paper 78-2 Age of Igneous Rocks along the Lennox Passage - St. Peter's Lineament, Southern Cape Breton Islands, by J. D. Keppie and P. K. Smith, 10 pages. (\$1.00)
- Paper 78-3 Geology of the Giant Lake Area, Southeastern Cape Breton Island, Nova Scotia, by P. K. Smith, 30 pages, 1 map. (\$2.00)
- Paper 78-4 Some Middle Devonian to Lower Carboniferous Rocks of Cape George, Nova Scotia, by J. D. Keppie, P. S. Giles, and R. C. Bohner, 37 pages. (\$2.00)
- Paper 78-5 Petrology of the Early Silurian Dunn Point and McGillivray Brook Formations, Arisaig, Nova Scotia, by J. D. Keppie, J. Dostal and M. Zentilli, 20 pages. (\$1.00)
- Paper 79-1 Petrology of the Late Precambrian Fourchu Group in the Louisbourg Area, Cape Breton Island, by J. D. Keppie, J. Dostal and J. B. Murphy, 18 pages. (\$1.50)
- Paper 79-2 Opencast Coal Reserves at Springhill, by B. Ward, 40 pages, 4 maps. (\$4.50)
- Paper 79-3 Geology of the Meat Cove Zinc Deposit, Cape Breton Island, by A. K. Chatterjee, 27 pages. (\$2.00)
- Paper 79-4 Minor and Trace Element Variations in Wisconsinian Tills, Eastern Shore Region, Nova Scotia, by R. R. Stea and J. H. Fowler, 30 pages, 3 maps. (\$10.00)
- Paper 79-5 Pleistocene Stratigraphy of the Miller Creek Section, Hants County, Nova Scotia, by R. Stea and D. Hemsworth, 16 pages. (\$3.00)
- Paper 79-6 Effects of Subsidence and Depositional Environment on the Formation of Lithotypes in a

- Hypautochthonous Coal of the Pictou Coalfield, by J. H. Calder, 23 pages. (\$3.00)
- Paper 79-7 Carbonate Banks of the Gays River Formation in Central Nova Scotia, by P. S. Giles, R. C. Bochner and R. J. Ryan, 57 pages, 1 map. (\$4.00)
- Paper 80-1 Geology of the Cape North Area, Northern Cape Breton Island, Nova Scotia, by A. S. Macdonald and P. K. Smith, 60 pages, 2 maps. (\$5.00) (Microfiche \$2.00)
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- Paper 82-1 Geology and Geochemistry of Selected Granitoid Plutons of Cape Breton Island, by S. M. Barr, G. A. O'Reilly and A. M. O'Beirne, 176 pages, 44 figures, 13 tables. (\$8.00) (Microfiche \$2.00)
- Paper 82-2 Metasomatic-Hydrothermal Mineral Deposits of the New Ross-Mahone Bay Area, Nova Scotia, by G. A. O'Reilly, E. J. Farley and M. H. Charest, 96 pages. (\$5.00) (Microfiche \$1.50)
- Paper 84-1 Petrology of Granitoid Rocks of the Boisdale Peninsula, Central Cape Breton Island, Nova Scotia, by S. M. Barr and J. R. D. Setter, 1986, 75 pages, includes Nova Scotia Department of Mines and Energy Map 84-2 folded in back pocket. (\$8.00) (Microfiche \$2.00)
- Paper 85-2 The formation of veins in greenschist facies rocks and the early deformation of the Meguma Group, Eastern Nova Scotia, by B. H. O'Brien, 1985, 35 pages. (\$3.00) (Microfiche \$1.00)
- Paper 86-1 Cretaceous Deposits of Nova Scotia, by G. B. Dickie, 1987, 54 pages. (\$15.00) (Microfiche \$3.00)
- Paper 89-1 Metallogenic Studies of South-eastern Cape Breton Island, by A. S. Macdonald, 1989, 99 pages, 3 figures in pocket. (\$20.00) (Microfiche \$3.00)
- Paper 89-2 Geology of the Mabou Highlands, by S. M. Barr and A. S. Macdonald, 1989. (In press)
- Paper 89-3 Coals of Western Cape Breton Island, by P. A. Hacquebard, D. Bromley and K. Gillis, 1989. (In press)
- ### REPORTS
- Report 75-1 Report of Activities of the Mineral Resources and Geological Services Division, 1974, by Nova Scotia Department of Mines, 75 pages. (\$1.00)
- Report 76-1 Drilling Logs of Government Core Drills, 1974, by I. MacDougall and D. W. Grimm, 73 pages. (\$1.00)
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OFM 88-040 Preliminary geological maps of the Cumberland Basin, Pugwash and Malagash (11E/13 and 11E/14), by R. J. Ryan, R. C. Boehner and A. Deal, 21 maps, scale 1:10 000.

OFM 88-041 Preliminary geological maps of the Cumberland Basin, Cape Chignecto and Parrsboro (21H/07 and 21H/08), by A. Deal, R. J. Ryan and R. C. Boehner, 13 maps, scale 1:10 000.

OFM 88-042 Preliminary geological maps of the Cumberland Basin, Springhill and Apple River (21H/09 and 21H/10), by R. J. Ryan, A. Deal, J. H. Calder

and R. C. Boehner, 24 maps, scale 1:10 000.

OFM 88-043 Preliminary geological maps of the Cumberland Basin, Amherst, (21H/16), by R. C. Boehner, R. J. Ryan and A. Deal, 11 maps, scale 1:10 000.

OFM 88-044 to 88-049 Mineral Resource Land Use Maps for Kings County (21A/10, 21A/15, 21A/16, 21H/01, 21H/01, 21H/02, 21H/08), by D. B. Hopper and H. J. Gillis, scale 1:50 000. (\$2.00, \$12.00 set).

OFM 88-050 Till Geochemistry of Northern Mainland Nova Scotia Clay Fraction Analyses, Antigonish and Guysborough Counties (Map Sheet 13-88), by R. G. Turner and R. R. Stea, scale 1:100 000. (\$2.00)

OFM 88-051 Till Geochemistry of Northern Mainland Nova Scotia Heavy Mineral Separate Analyses, Antigonish and Guysborough Counties (Map Sheet 13-88), by R. G. Turner and R. R. Stea, scale 1:100 000. (\$2.00)

OFM 89-001 Geological Map of Kentville-South Alton Quadrangle, compiled by S. A. Ferguson, 1987-1988, scale 1:10 000. (\$2.00)

OFM 89-002 Geological Map of West Gore Quadrangle, by R. G. Moore, 1988, scale 1:10 000. (\$2.00)

OFM 89-003 Geological Map of Newport Corner Quadrangle, by R. G. Moore, 1988, scale 1:10 000. (\$2.00)

OPEN FILE REPORTS

The following Open File Reports are available for purchase from the Library in hard copy. Microfiche copies may be purchased from Precision Microfilming Services, 6100 Young Street, Halifax, Nova Scotia B3K 2A4.

OFR 329 The Glencoe Limestone and Dolomite Survey, by D. J. MacNeil, 1977, 252 pages, 12 maps. (\$15.00)

OFR 599 Metallic Mineral Occurrences Map and Data Compilation, Central Nova

- Scotia - map sheets 11D and 11E by M. Ponsford and N. A. Lyttle, 1984, 21 pages, 2 maps. (\$3.00)
- OFR 600 Metallic Mineral Occurrences Map and Data Compilation, Eastern Nova Scotia - map sheets 11F, 11G, 11J, 11K, 11N, by M. Ponsford and N. A. Lyttle, 1984, 23 pages, 2 maps. (\$3.00)
- OFR 601 Metallic Mineral Occurrences Map and Data Compilation, Western Nova Scotia - map sheets 20O, 20P, 21A, 21B, 21H, by M. Ponsford and N. A. Lyttle, 1984, 21 pages, 2 maps. (\$3.00)
- OFR 603 Preliminary Feasibility Study for an Underground Gold Mining Operation in Central Nova Scotia, by Nova Scotia Department of Mines and Energy, 1984, 62 pages, 2 maps. (\$5.00)
- OFR 605 Regional Lake Sediment Survey of the Meguma Zone, Southern Nova Scotia: New Analytical Data, by P. J. Rogers, M. A. MacDonald and D. W. Rigby, 1985, 65 pages, 2 maps. (\$5.00)
- OFR 606 Industrial Mineral Occurrences Map and Data Compilation, Central Nova Scotia - map sheets 11D, 11E by M. Ponsford, G. DeMont and N. A. Lyttle, 1985, 22 pages, 2 maps. (\$4.00)
- OFR 607 Industrial Mineral Occurrences Map and Data Compilation, Eastern Nova Scotia - map sheets 11F, 11G, 11J, 11N, by M. Ponsford, G. DeMont and N. A. Lyttle, 1985, 29 pages, 2 maps. (\$4.00)
- OFR 608 Industrial Mineral Occurrences Map and Data Compilation, Western Nova Scotia - map sheets 20O, 20P, 21A, 21B, 21H, by M. Ponsford, G. Demont and N. A. Lyttle, 1985, 21 pages, 2 maps. (\$4.00)
- OFR 621 Effects of Location on Mine Development Potential: Nova Scotia's Competitive Position in Canada, by D. W. Davis, B. W. MacKenzie and M. L. Bilodeau, 1985, 103 pages. (\$15.00)
- OFR 648 Current Market Economics of the Strontium Minerals by Metals Economic Group of Halifax, Nova Scotia and Boulder, Colorado, 1985, 54 pages. (\$5.00)
- OFR 650 Preprint of Paper 85-3. Guide to the Granites and Mineral Deposits of Southwestern Nova Scotia, edited by A. K. Chatterjee and D. B. Clarke, 1985, 264 pages. (\$15.00)
- OFR 651 Gypsum property, Ownership and Leases, by M. W. G. King, 1985, 140 pages. (\$10.00)
- OFR 656 The Development Potential for Nova Scotia's Offshore Aggregate and Placer Resources, by J. Fowler and C. Miller, 1985, 69 pages. (\$10.00)
- NOTE: As of January 1986, all new open file reports will have a report number which will be assigned sequentially based upon the year the report is received by the Department.
- OFR 86-010 Study of Markets for Aggregate Materials accessible from Nova Scotia and New Brunswick, by ADI Limited. (\$10.00)
- OFR 86-012 A Study of Industrial Minerals Used in Oil and Gas Exploration on the Eastern Canadian Offshore, by Jacques, Whitford and Associates and Cleland, Dunsmuir Consulting Limited. (\$17.00)
- OFR 86-013 Study of Markets for Silica and Silica Sands Accessible from Nova Scotia and New Brunswick, by ADI Limited. (\$10.00)
- OFR 86-019 Compilation of drillhole information from open assessment reports available to the end of December, 1985: Central Nova Scotia - map sheets 11D, 11E. (\$10.00)
- OFR 86-020 Compilation of drillhole information from open assessment reports available to the end of December, 1985: Eastern Nova Scotia - map

sheets 11F, 11G, 11J, 11K, 11N.
(\$10.00)

OFR 86-021 Compilation of drillhole information from open assessment reports available to the end of December, 1985: Western Nova Scotia - map sheets 20O, 20P, 21A, 21B, 21H. (\$10.00)

OFR 86-025 The Gypsum Industry in Nova Scotia - Present Status and Future Prospects, by R. E. Wright and J. H. Brown. Prepared for Nova Scotia Department of Mines and Energy by Center for Resource Studies, Queen's University, 1985, 125 pages. (\$15.00)

OFR 86-039 Agricultural Gypsum Project, by P. Luke, 1986, 9 pages. (\$3.00)

OFR 86-054 The U.K. Experience on the Effects of Offshore Sand and Gravel Extraction on Coastal Erosion and the Fishing Industry, by R. Warren Drinnan and D. G. Bliss, Dobrocky Sea Tech Limited, August 1986, 90 pages. (\$10.00)

OFR 87-002 Market Analysis for New Brunswick, Nova Scotia and Newfoundland Dimension Stone, by the DPA Group Incorporated in association with Jacques Whitford & Associates Limited, 1987, 66 pages. (\$10.00)

OFR 87-005 Report on the Potential Stone Quarry, MacKenzie Farm, Hardwood Hill, Pictou County, Nova Scotia, by G. Dickie, 1986, 37 pages. (\$5.00)

OFR 87-023 Report on the English Property (McKeen Quarry), Pictou County, by G. B. Dickie, 1987, 12 pages. (\$5.00)

OFR 87-027 Potential Crushed Stone Deposits on Tidewater in Nova Scotia, by G. B. Dickie, 1987, 15 pages. (\$5.00)

OFR 87-032 Sulphur in Nova Scotia: Pugwash and Hilden Occurrences, by D. C. Carter, R. C. Boehner and G. C. Adams, 1987, 7 pages. (\$5.00)

OFR 88-013 A Study of U. S. East Coast Industrial Mineral Markets for New Brunswick, Newfoundland and Nova

Scotia, by Metals Economics Group, 1988. Prepared for Mineral Policy Sector, Energy Mines and Resources Canada, 286 pages. (\$15.00)

OFR 88-039 Marine Transport Study for Nova Scotia, by Leslie MacIntyre Maritime Associates Inc., May 1988. Prepared for Mineral Policy Sector, Energy, Mines and Resources Canada, 38 pages. (\$5.00)

OFR 88-040 Aggregate Market Study for New Brunswick and Nova Scotia, by ADI Limited, 1988. Prepared for Mineral Policy Sector, Energy, Mines and Resources Canada, 309 pages. (\$17.00)

OFR 88-055 Multielement Ratings Maps for Meguma Zone Lake Sediments, by P. J. Rogers, 1989, 34 pages, 3 maps. (\$5.00)

OFR 88-056 An Assessment of the Hydrocarbon and Compressed Air Storage Potential of Nova Scotia Salt Deposits, by Nolan, Davis & Associates Ltd., 1988, 195 pages. (\$20.00)

OFR 88-057 Gypsum, Anhydrite Potential, Meadows Road Area, Cape Breton County, by G. Adams, 1988, 29 pages. (\$5.00)

OFR 88-059 Interpretation of Till Geochemical Data in Nova Scotia, Canada, Using Mapped Till Units, Multi-Element Anomaly Patterns, and the Relationship of Till Clast Geology to Matrix Geochemistry, by R. G. Turner and R. R. Stea, 1988, 39 pages. (\$5.00)

OFR 88-063 An Assessment of the Hydrocarbon and Compressed Air Storage Potential of Nova Scotia: A Summary, by Nolan, Davis & Associates Ltd., 1988, 22 pages. (\$3.00)

OFR 89-001 Lithogeochemistry of the Eastern Portion of the South Mountain Batholith, Nova Scotia, Map Sheets 11D/05, 11D/12, 11D/13, 21A/09, 21A/10, 21A/15, 21A/16 and parts of 21H/01 and 21H/02, by L. J. Ham, S. W. Marsh, M. C. Corey,

R. J. Horne and M. A. MacDonald,
62 pages, 2 maps. (\$15.00) (Disk
copy of geochemical data \$5.00)

OFR 89-003 Open file report on selected mineral
occurrences of the Antigonish area,
NTS 11E/08, 09 and 16, by K. E.
Northcote, G. DeMont and A.
Armitage, February 1989, 184 pages
plus tables. (\$15.00)

OFR 89-004 Open file report on selected mineral
occurrences of Southern Cape Breton
Island, Nova Scotia, NTS 11F/10,
11F/15, 11F/16, 11K/01, 11K/02,
by K. E. Northcote, G. DeMont and
A. Armitage, March 1989, 94 pages
plus tables. (\$10.00)

OFR 89-005 Open file report on selected mineral
occurrences of the Cobequid area,
Nova Scotia, NTS 11E/05, 11E/06,
11E/10, 11E/11, 11E/12, 21H/07,
21H/08, by K. E. Northcote, G.
DeMont and A. Armitage, March
1989, 180 pages plus tables. (\$15.00)

OFR 89-006 Summary report on quarry stone used
in the construction of Dominion
Building, Halifax, N. S., by G. B.
Dickie, 1989, 16 pages. (\$3.00)

OUTSIDE PUBLICATIONS AND MAPS AVAILABLE FOR PURCHASE

OP-1 Malagash Salt, compiled and edited
by J. R. MacQuarrie, c.1975, 1981.
(\$5.00)

Geological Association of Canada/Mineralogical
Association of Canada Guidebooks for Field
Excursions (Fredericton, May 15-17, 1985).

OP-2 Trip No. 1 Appalachian Geotraverse
(Canadian Mainland); J. D. Keppie,
K. Currie, J. B. Murphy, et al., 181
pages. (\$15.00)

OP-4 Trip No. 10 Igneous and
Metamorphic Geology of the Cape
Breton Highlands; S. M. Barr, R. A.
Jamieson, R. D. Raeside. (\$5.00)

OP-5 Trip No. 11 Turbidite-Hosted Gold
Deposits, Meguma Domain, Eastern

Nova Scotia; P. K. Smith, S. J.
Haynes, B. E. Jones. (\$7.00)

OP-6 Trip No. 14 Lithostratigraphic,
Physical Diagenetic and Economic
Aspects of the Pennsylvanian
Permain Transition Sequence of
Prince Edward Island and Nova
Scotia; H. W. van de Poll, J. R.
Degrace, R. J. Ryan. (\$7.00)

OP-7 Basins of Eastern Canada and
Worldwide Analogues, Programme
with Abstracts, Basins of Eastern
Canada and Worldwide Analogues
Symposium, August 13-15, 1986,
Halifax, Nova Scotia, 132 pages.
(\$8.00)

OP-8 Atlantic Geoscience Society, Special
Publication Number 3. Occupational
Safety in the Geosciences,
Programme with Abstracts: A
Seminar and Panel Discussion on
Safety-Related and Their Legal
Topics Concerning Geoscientists and
Their Work Environments, Organized
by the Atlantic Geoscience Society,
and Co-Sponsored with the
Department of Geology, Dalhousie
University, The Nova Scotia
Chamber of Mineral Resources, The
Atlantic Provinces Council on the
Sciences, and Geomarine Associates
Limited, Dalhousie University,
Halifax, Nova Scotia, September 25,
1985, 100 pages. (\$2.00)

OP-9 Atlantic Geoscience Society, Special
Publication Number 4.
Carboniferous-Jurassic Sedimentation
and Tectonics: Minas, Cumberland
and Moncton Basins, Nova Scotia and
New Brunswick, by R. C. Boehner,
J. H. Calder, D. C. Carter, H. V.
Donohoe, Jr., L. Ferguson, R. K.
Pickerill, and R. J. Ryan; a Field
Trip Guidebook from the Basins of
Eastern Canada and Worldwide
Analogues Symposium, Halifax,
August 1986, 122 pages. (\$8.00)

OP-10 Atlantic Geoscience Society, Special
Publication Number 5 (CSPG Memoir
12). Sedimentary Basins and Basin-
Forming Mechanisms, edited by C.
Beaumont and A. J. Tankard; from

- Basins of Eastern Canada and Worldwide Analogues Symposium, Halifax, August 1986, 527 pages. (\$70.00)
- OP-11 Atlantic Geoscience Society, Colloquium '88, Antigonish, N. S. (Abstracts of Papers). (\$4.00)
- OP-12 Contributions to the geology of the Meguma Terrane, Nova Scotia, edited by J. D. Keppie. Special issue of Maritime Sediments and Atlantic Geology, v. 22, no. 1, 1986, 135 pages. (\$10.00)
- OP-13 Quaternary Glaciations, Geomorphology and Sea Level Changes: Bay of Fundy Region; NATO Advanced Study Institutes Programme, International Advanced Course on Late Quaternary Sea Level Correlations and Applications, July 19 to 30, 1987, Halifax, Nova Scotia; Symposium Field Guide, 79 pages. (\$10.00)
- OP-14 The Mining Society of Nova Scotia 1887-1987, by D. Pigot. Published by the Mining Society of Nova Scotia, June 1987, 125 pages. (\$20.00) (Paperback: \$10.00)
- OP-15 Contributions on the geology of granitoid and host rocks, Meguma Terrane, Nova Scotia, edited by D. J. Kontak and S. M. Barr. Special issue of Maritime Sediments and Atlantic Geology, v. 24, no. 1, 1988, 121 pages. (\$10.00)

SAMPLE CATALOGUES

- SC 89-1 Nova Scotia's Dimension Stone for Designers, Developers, Quarries, 1989. (\$100.00)

¹ NOTE: Maps 82-6 to 82-9 may be purchased individually or as a set for \$25.00

² NOTE: Maps 85-3 to 85-6 may be purchased individually or as a set for \$10.00